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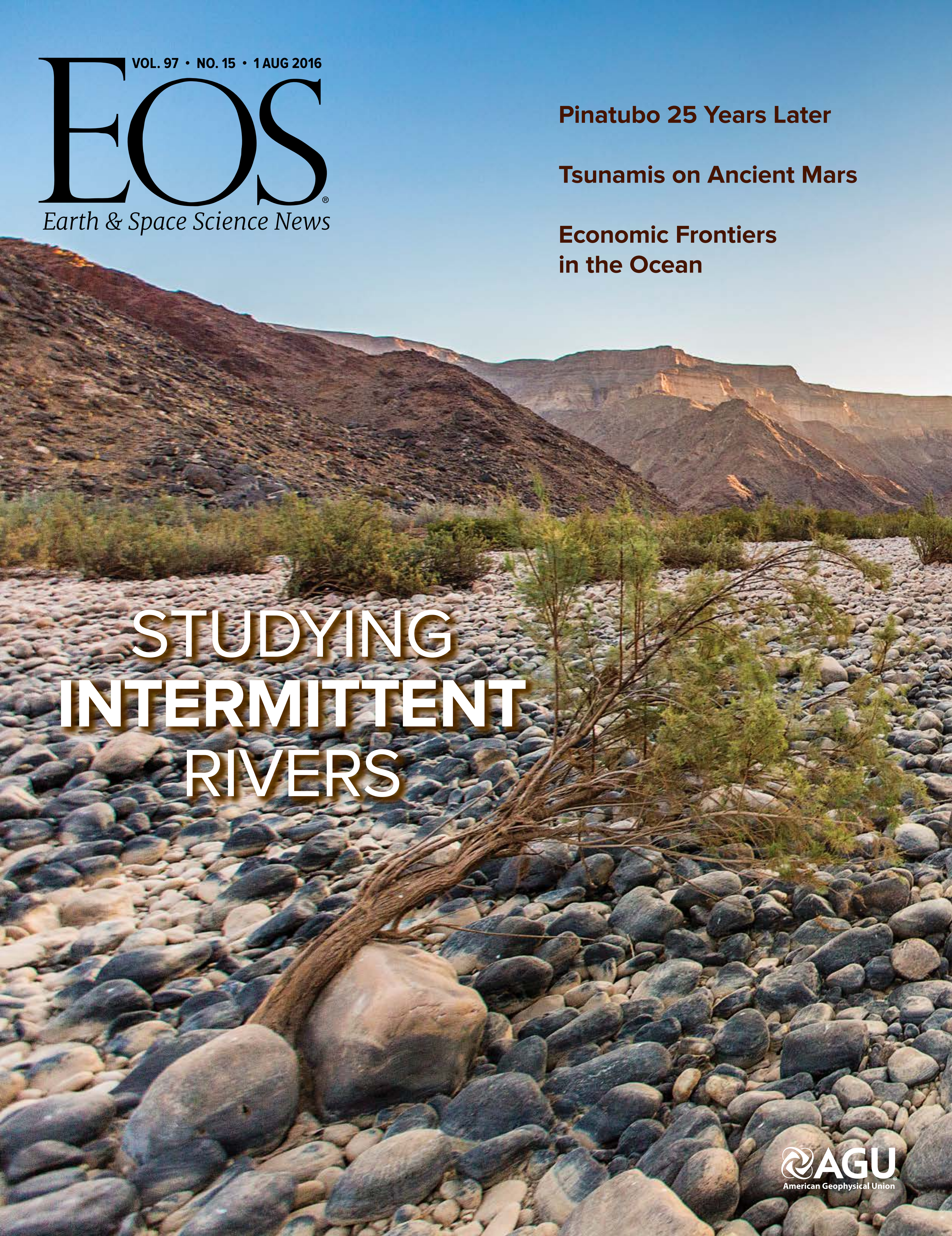
EOS

Earth & Space Science News

Pinatubo 25 Years Later

Tsunamis on Ancient Mars

Economic Frontiers in the Ocean



STUDYING **INTERMITTENT** RIVERS

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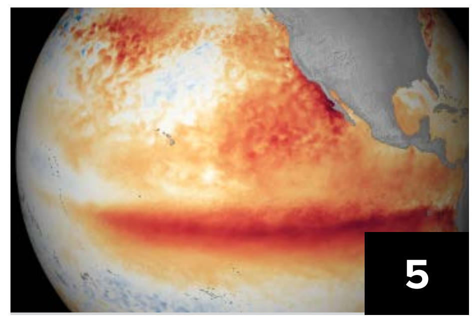

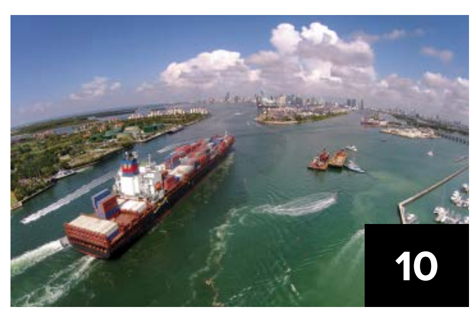

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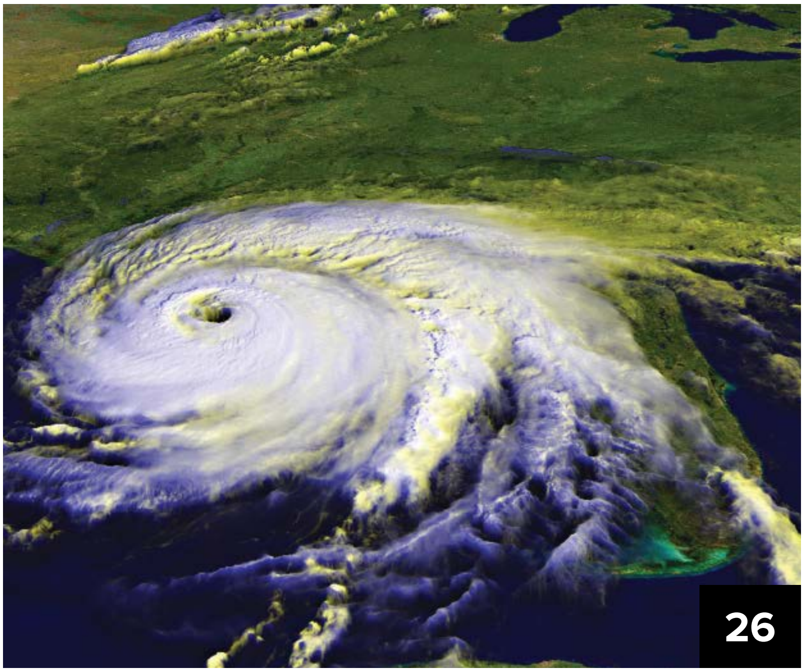

On the Cover

The Fish River in southern Namibia floods in late summer, but dries into a series of pools the rest of the year. Credit: Teagan Cunniffe.

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Christine W. McEntee, Executive Director/CEO

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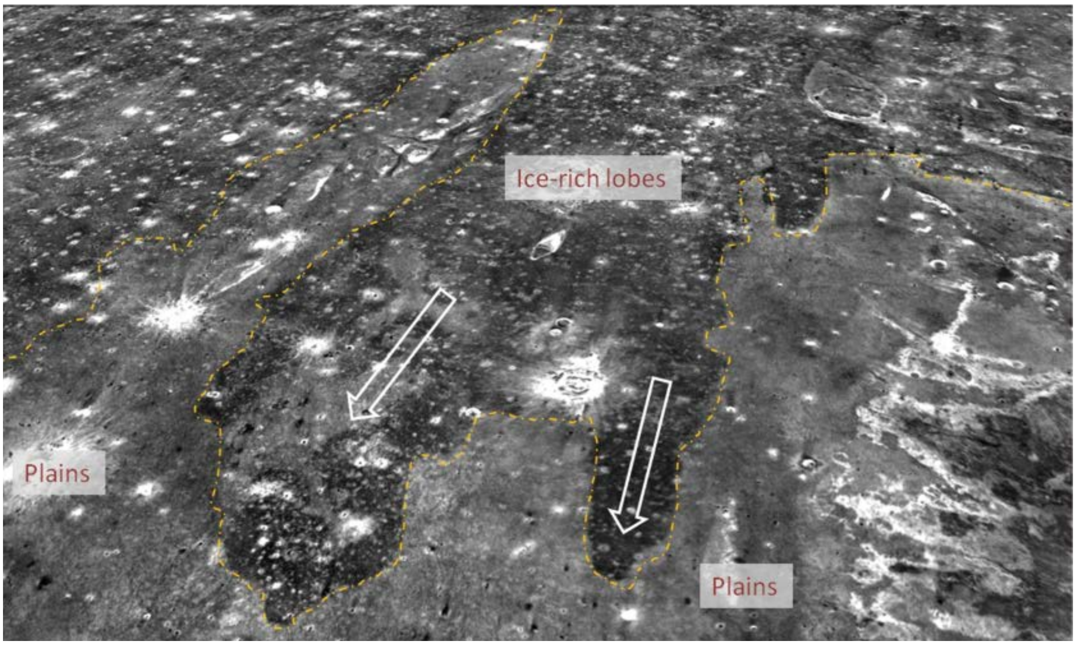
Tsunamis Splashed Ancient Mars



Alexis Rodriguez, NASA, JPL-Caltech, Arizona State University

This thermal image shows elevated ice-rich lobes likely deposited by the second of two tsunamis suspected to have inundated Martian shorelines billions of years ago. The lobes, outlined in yellow and marked with arrows indicating flow direction at the time they formed, each extend approximately 250 kilometers, roughly the distance from Baltimore to New York City.

The northern hemisphere of Mars hosts a vast, smooth basin that looks as though it could have once held an ocean. However, the basin lacks topographic features of an obvious and complete ancient shoreline, so planetary scientists have debated this tantalizing possibility for decades.

Now a team of researchers has given extraordinary new scrutiny to these landforms. As a result, the scientists have identified huge deposits of rocks and sediments, backwash gullies, and other topographic features on the edges of the basin. They report that these features were likely produced when tsunamis raced through an ocean in the basin and scarred shorelines roughly 3.4 billion years ago.

The evidence suggests that two separate tsunamis stormed through the ocean—which encircled the north pole and could have been one third the size of the entire globe—some millions of years apart. The new signs of a Martian ocean sustained for millions of years between meteorite impacts bolster the possibility that the Red Planet offered a tolerable environment for life at the time, the researchers said.

"It is difficult to imagine summer Californian beaches on early Mars, but try picturing Norwegian iced fjords during a particularly cold winter and maybe you'll get a more accurate picture," said Alberto Fairén of the Center of Astrobiology in Madrid, Spain, who participated in the research and is a visiting scientist at Cornell University in Ithaca, N.Y.

> Signs of a Martian ocean sustained for millions of years between meteorite impacts bolster the possibility that the Red Planet offered a tolerable environment for life.

Fairén, first author Alexis Rodriguez of the Planetary Science Institute in Tucson, Ariz., and their colleagues published the analysis on 19 May in *Nature Scientific Reports* (http://go.nature.com/1VQBQpQ).

Mighty Waves Resculpted Ocean Shore

The team used three data sets—visible images, altimeter data, and thermal images—from the Mars Reconnaissance Orbiter and the Mars Global Surveyor to probe a small section of the northern plains. The images show two different populations of semicircular sedimentary deposits called lobes, one of which is associated with backwash channels, and massive boulders aligned within those channels.

From the features, Rodriguez and his colleagues have been able to piece together a detailed story of what transpired to create those landforms long ago.

The first tsunami swept past the shoreline, the team contends, entraining with it boulders as wide as 10 meters, until it hit surrounding highlands. There the water rolled uphill and left sediments behind until it retreated into the ocean. As the waters washed inward, they gouged enormous backwash channels along the shore and aligned boulders within those channels.

Big Chill

During the thousands of millennia between that tsunami and the next, Mars underwent serious global cooling, the team asserts. During this time, the ocean partially froze and much of it evaporated, causing its sea level to drop by about 300 meters and the shorelines to retreat.

When a second projectile eventually smacked into the smaller, ice-rich ocean, a second tsunami washed ashore. Unlike the previous event, this tsunami didn't realign boulders or even leave backwash channels. "You can imagine that if you have water and you spill it over a frozen surface, it will freeze over very fast because it's thin," said Rodriguez. "So the tsunami basically freezes in situ and it doesn't enter a backwash phase. It just stays there."

In their paper, the researchers compare the icy, more recent tsunami to an event that was recorded in 2013 in the Codette Reservoir in Saskatchewan, Canada. "The ice surge triggered catastrophic ice-rich floes and led to

the emplacement of enormous lobate fronts, which are very similar to those shown in our area of study on Mars," said Fairén.

Out of This World Tsunamis

Despite the cooler conditions at the time of the second impact and tsunami, both inundations went way off the charts compared with typical tsunamis on Earth. The waters surged as far as 650 kilometers inland and submerged as many as a million square kilometers of land. "These run-up distances and inundation areas are enormous by terrestrial standards," the team noted in its paper.

The researchers chalk up the tsunamis to strikes by meteorites big enough to have left behind craters roughly 30 kilometers in diameter—a scale of impact that took place with about the right frequency back then to support this Martian tsunami hypothesis, the team reported.

> If the ocean once contained life, organisms might remain encased within the icy lobes.

Implications for Extraterrestrial Life

To Greg Michael of the Free University of Berlin in Germany, who was not involved in the research, the evidence for a lingering ocean on early Mars suggests exciting implications. "This obviously is very interesting if you want to talk about the possibility of life," he said.

If the ocean once contained life, organisms might remain encased within the icy lobes piled up by the more recent tsunami, Rodriguez said. Even if those lobes lack frozen microbes, they might tell scientists whether the chemistry of the ancient ocean was at least conducive to life.

What's more, said coauthor and retired scientist Kenneth Tanaka of the U.S. Geological Survey in Flagstaff, Ariz., the Curiosity mission's presence in Gale crater just a couple of hundred kilometers away from the lobes has already demonstrated the feasibility of a future rover reaching the tsunami site. The new analysis "will definitely move the compass toward [the icy lobes]," he added, "but whether the exploration committees would point NASA to go toward these, it's hard to say."

By **Shannon Hall,** Freelance Writer; email: hallshannonw@gmail.com

Report Touts White House Science Impact

White House/Pete Souza

White House science adviser John Holdren (right) meets with President Barack Obama in the Oval Office prior to the release of a March 2009 Presidential Memorandum on Scientific Integrity.

A White House list of 100 top science, technology, and innovation achievements of the Obama administration includes progress related to the Earth and space sciences in understanding and combating climate change and boosting energy efficiency and clean energy production.

The recently released report (see http://1.usa.gov/28UVuLG) highlights the administration's Climate Action Plan, issued in 2013; its successful efforts toward the landmark United Nations climate agreement in Paris last year; and a goal recently established with 19 other nations and the European Union to double their governments' investments in clean energy research and development by 2021.

Other Earth and space science–related items on the list include a comprehensive strategy for the Arctic region, a national strategy for Earth observations, a national ocean policy, efforts to increase resilience of U.S. communities to natural hazards, and the administration's 2009 memorandum on scientific integrity.

Longest-Serving Science Adviser

The 21 June report noted that earlier that month, White House science adviser John Holdren became "the longest-serving President's Science Advisor since Vannevar Bush pioneered a similar role while serving Presidents Roosevelt and Truman during and after World War II."

Holdren assumed the positions of White House science adviser and director of the White House Office of Science and Technology Policy (OSTP) on 19 March 2009. On 18 June he had served in those positions for 7 years, 2 months, and 29 days, breaking the previous record for time served in both offices set by John Marburger III. Marburger advised the George W. Bush administration and was its OSTP director from 23 October 2001 to 20 January 2009.

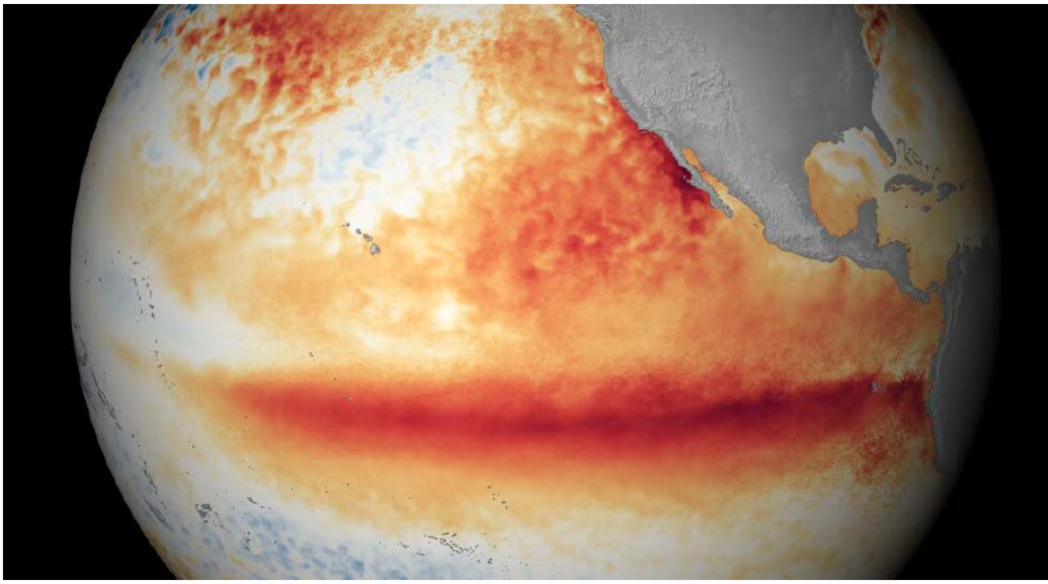
By **Randy Showstack,** Staff Writer

El Niño Will Increase Atmospheric Carbon to Record Levels

This year, for the first time, atmospheric carbon dioxide (CO_2) concentrations recorded at Mauna Loa, Hawaii, will exceed 400 parts per million (ppm) and remain above this level indefinitely. This sustained high level is due to El Niño effects, which disrupt carbon sinks and increase emissions from forest fires, according to findings published on 13 June in *Nature Climate Change* (http://go.nature.com/296UOpy).

In 2015 the annual average concentration passed the 400-ppm mark, but monthly concentrations fell back to about 397.5 ppm during the summer and fall. But now there's no going back to pre-400-ppm levels, explained lead author Richard Betts of the Met Office Hadley Centre for Climate Science and Services and the University of Exeter, both in the United Kingdom.

The 400-ppm mark would have been exceeded "next year or later anyway, but El Niño has caused the CO_2 to rise extra fast this year," Betts said. "We hit the mark earlier than expected."



NOAA

Satellite image showing the average sea surface temperature during the 2015–2016 El Niño. Red indicates warmer than average temperatures.

El Niño and Emissions

In a normal year, water in the eastern Pacific Ocean is about 8°C cooler than in the western Pacific. This is because wind patterns typically push water to the west, bringing cool, deep water to the surface of the eastern Pacific.

El Niño dramatically alters this cycle—winds get weaker, and warm water slumps into the eastern Pacific, raising ocean temperatures. The cascade of ensuing weather patterns increases drought and fire in the tropical western Pacific.

The damage to carbon sinks from drought and fire has the additional effect of slowing carbon removal over time.

For example, the 1997 El Niño caused dry conditions in Indonesia and Malaysia, which exacerbated human-caused fires and ignited carbon-rich peatlands that burned out of control for months, contributing to an anomalously high annual atmospheric CO_2 growth rate. Starting last year, drought conditions in Indonesia, brought on by the 2015–2016 El Niño, also spurred expansive fires (see page 6 of this issue).

A Threshold Crossed

Models have simulated the strength of El Niño effects on sea surface temperature, but no previous study had predicted the total contributions of El Niño effects to atmospheric CO_2 levels.

Betts and his colleagues focused on the 2015–2016 El Niño, using data collected at the historic Mauna Loa Observatory in Hawaii, where rising atmospheric CO_2 was first recorded in 1958. The team built a statistical model using multiple linear regression analysis to relate sea surface temperatures and atmospheric CO_2 concentrations.

According to the findings, CO_2 levels will break historic records this year. The monthly mean CO_2 concentration at Mauna Loa is predicted to remain above 400 ppm year-round, and the El Niño effect is estimated to contribute an additional 0.5–1.5 ppm to the usual year-by-year rise of about 2 ppm. This small increase lasts only as long as El Niño itself, perhaps with a small lag, but the damage to carbon sinks from drought and fire has the additional effect of slowing carbon removal over time.

Shifting Baselines

"All surface monitoring stations around the world have now seen baseline episodes of 400 ppm or more," said Paul Fraser of the Cape Grim Baseline Air Pollution Station in Smithton, Tasmania, Australia. Cape Grim hit this record for the first time in May, and Fraser expected that observations will remain high.

With the exception of monitoring stations at high latitudes in the Arctic, where levels might not hit 400 ppm every month, levels around the globe are expected to exceed 400 ppm for hundreds of years, if not longer, added Fraser, who was not affiliated with the study. Because natural sinks remove CO_2 only gradually, atmospheric levels will remain high even if humans curb emissions.

"Carbon dioxide levels will still increase unless we dramatically reduce emissions," said study coauthor Ralph Keeling of the Scripps Institution of Oceanography in La Jolla, Calif. "We can cut the growth rate in atmospheric carbon dioxide concentrations, but total levels will increase unless emissions are cut by about 50%."

By **Amy Coombs,** Editorial Intern

The 2015 Indonesian Fires: Less Carbon Release Than Was Thought

NASA/Kevin C. Ryan

A scientist takes a smoke sample from a smoldering peat fire in Kalimantan, Indonesia.

Last fall, fires driven by extreme El Niño conditions swept through the peatlands of Indonesia's Central Kalimantan province, with catastrophic effects on air quality throughout Southeast Asia, including air pollution up to 10 times the level considered hazardous to human health and visibility in some areas reduced to 50 meters.

Emissions from fires like these have given Indonesia a notorious place on the list of the world's largest contributors to climate change—it's currently ranked the third worst. A NASA-funded collaboration between Indonesian and American scientists, however, has found evidence that questions this ranking. Preliminary results presented recently at the Society of Wetland Scientists' annual meeting in Corpus Christi, Texas, suggest that Indonesia's peat fires may produce less greenhouse gas than previously believed (see http://bit.ly/iIndo-fires-SWS16).

Up in Smoke

Peat forms in wetlands where wet, oxygen-poor conditions prevent plant material from fully decomposing. As generations of plants grow, die, and then only partially decompose, their remains pile up into a thick layer of organic matter, called peat, which acts as a carbon sink.

Indonesia—primarily Kalimantan, the Indonesian region of Borneo—is home to half of the world's tropical peatlands. In the mid-1990s the Indonesian government's Mega Rice Project (see http://bit.ly/MegaRice-NatGeo) drained and cleared more than a million hectares of Kalimantan's peat forest in an unsuccessful attempt to convert it to agriculture, which has led to widespread annual fires in the region as the carbon-rich peat dries out and becomes flammable (see page 5 of this issue).

> Fires in degraded peatlands like the drained peat swamp forests of Indonesia have a profound influence on the environment.

In fall 2015 a particularly strong El Niño drove severe dry conditions in the region that led to the worst fires in nearly 20 years, with particulate pollution from the smoke reaching 10 times the amount considered hazardous to human health. Current estimates of the amounts of various greenhouse gases produced by peat fires come from lab experiments, and on the basis of those, Indonesia's fires make it the world's third-largest carbon emitter. Without its forest fires, however, Indonesia would rank around 22nd, according to Erianto Putra of South Dakota State University in Brookings, the climate scientist who presented the data at the meeting.

To obtain a more accurate, field-based analysis of the smoke's components, Putra's colleagues imported a portable infrared spectrometer and other equipment into Indonesia from the United States. The researchers took the spectrometer out into still-smoldering peatlands, where they collected samples of the smoke and analyzed its makeup.

"Our ministry of forestry is working on monitoring greenhouse gas emissions, but they still have questions about the emissions from peatland fires," says Putra. "We are the first to conduct research on the smoke from peat fires in Indonesia, and we want to fill in this critical gap" by answering the ministry's questions.

Understanding Peat Fires

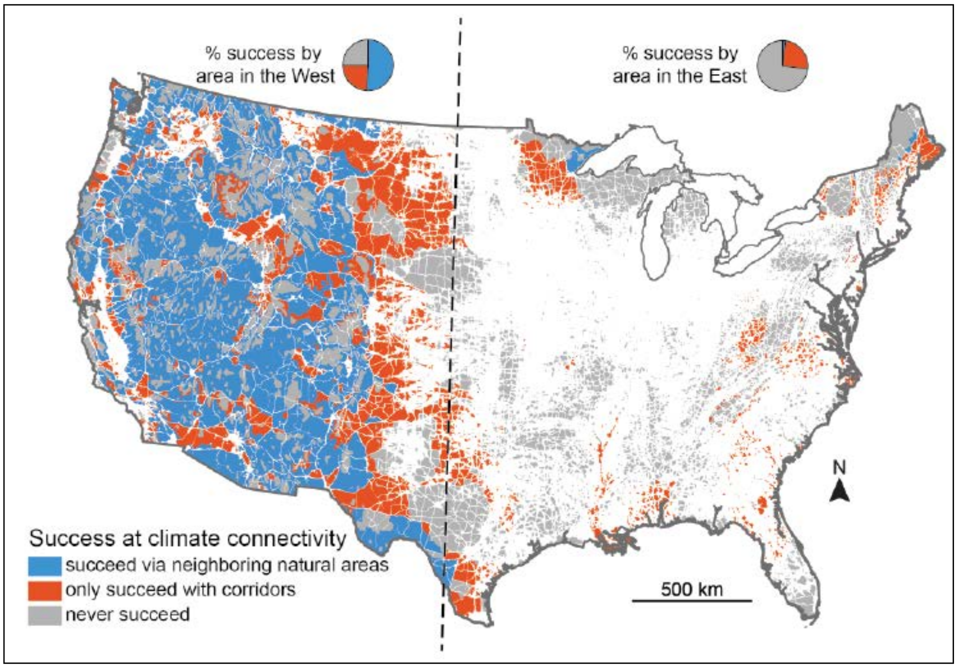
Preliminary results presented at the wetlands meeting on 3 June show that burning peat emits 8% less carbon dioxide and 55% less methane than previously believed. While this doesn't make the most recent fires' impacts on Southeast Asia any less catastrophic, it does mean that Indonesia may be shouldering an unfair share of blame for the world's carbon woes.

"Fires in degraded peatlands like the drained peat swamp forests of Indonesia have a profound influence on the environment, both locally and globally," said plant ecologist Brian Benscoter of Florida Atlantic University in Boca Raton, chair of the Society of Wetland Scientists' peatlands section. The prolonged smoldering of the dense organic soil, he explained, produces heavy smoke that can remain low in the atmosphere for long periods, creating visibility hazards and threatening the health of local communities.

"Research like that of Dr. Putra and his colleagues is helping to inform gaps in our current understanding of smoke emissions during peatland burning in tropical peatlands and beyond," Benscoter said. The peat fires offer "a strong and compelling example of what can happen in degraded peatlands and why these important ecosystems need to be restored or conserved globally."

By **Rebecca Heisman,** Freelance Science Journalist; email: rebecca.heisman@gmail.com

Habitat Fragmentation Prevents Migration During Climate Change



PNAS, 2016, doi:10.1073/pnas.1602817113

Can a species move from a warming habitat to a cooler zone without hitting a city, hot desert, or impenetrable agricultural zone? The West has adjacent or closely linked habitats (blue) and areas linked with corridors (red). Most habitats in the East are entirely fragmented (gray).

As climates change over the next century, many species of plants and animals will be forced to change their habitat ranges to survive. According to the first continent-wide geospatial study of climate connectivity—a measure of the migratory routes between warm and cool zones—only 2% of the eastern United States contains the connected green space needed for animals to find new homes. The findings appeared on 13 June in the *Proceedings of the National Academy of Sciences of the United States of America* (see http://bit.ly/PNAS-climate-connect).

"The East Coast is in dire shape because habitat is already in very small patches," says study author Jenny McGuire, a research scientist at the Georgia Institute of Technology in Atlanta. "We have a nice swath of intact land around the Appalachian Mountains, but other natural areas are patchy and fragmented." This keeps animals—and the plant seeds they may carry—from moving to cooler areas where they can maintain a temperature similar to the climate in their current habitat.

Fragmented Green Space

McGuire and her colleagues set out with an ambitious plan to identify all spans of green space in the United States where species can migrate from a warmer to a cooler habitat without having to traverse extreme deserts, cold mountain peaks, or disturbed areas like cities and agricultural lands.

They used an algorithm to consider temperature change over time and then mapped cooler areas that species in warming locations could access. Then they measured how close populations are to where they could go, using corridor lengths of no longer than 100 kilometers.

According to their findings, about 50% of the American West can support migration. However, the landscape on the East Coast remains too fragmented for plants and animals to change their range—only 2% of the eastern plains and coastal areas have cool sites adjacent to warm zones.

Eastern species able to traverse 10-kilometer corridors can enjoy 16% climate connectivity, and those that migrate more than 100 kilometers will find 27% of the landscape to be accessible. In contrast, when allowing for 100-kilometer migratory routes in the West, climate connectivity rose to 75%.

Although surprised by the dire state in the East, David Ackerly of the University of California, Berkeley predicted that connectivity would be better in the West because of the rugged terrain. "If you live in a mountain range and temperatures begin to warm, you just move a short distance uphill," said Ackerly, who is not affiliated with the study. "But on a large span of flat landscape, like the plains or coastal hills, you have to traverse a greater distance to reach higher altitude and cooler climate."

Connecting Shrinking Habitats

Prior studies have mapped routes between dwindling populations to help increase interbreeding and genetic diversity. This strategy supports a long list of species, including threatened plants, which disperse to moist areas by spreading pollen, and predators like foxes and mountain lions, which migrate according to the shifting ranges of food species and distant mates.

It also helps local species like the gopher tortoise (*Gopherus polyphemus*), which is currently protected by the Endangered Species Act because of the disturbance of sandy pine forests in Florida and Georgia, where it digs burrows that shelter more than 300 other types of animals. The threatened seepage salamander (*Desmognathus aeneus*) is similarly found only in small areas of Tennessee, North Carolina, Georgia, and Alabama, but these ranges are predicted to shrink because of climate change (see http://bit.ly/PLOS-ONE-salamander).

"The East Coast is in dire shape because habitat is already in very small patches."

Corridor projects that create greenways for migration can help such isolated populations breed, but they rarely consider long-term range changes that will alter habitat boundaries as temperatures warm.

However, "the current findings give us a 30,000-foot view of the problem" because they consider climate conditions, says Ackerly. "By tracing connectivity across coastal and mountainous regions, we can see areas where restoration work would significantly expand connectivity in the East."

By **Amy Coombs,** Editorial Intern

Robert L. "Bob" Carovillano (1932–2015)

Boston College Faculty and Staff Photographs, John J. Burns Library, Boston College

Robert L. Carovillano

Robert Carovillano, an internationally recognized theoretical space physicist and inspiring teacher and mentor of numerous undergraduate and graduate students, died suddenly on 15 October 2015 in Delray Beach, Fla. He was 83 years old.

Bob received his B.S. degree from Rutgers University and M.S. and Ph.D. degrees in theoretical physics from Indiana University. His thesis was on the theory of the nuclear force, and his early publications were in nuclear physics and quantum field theory. He joined the Boston College (BC) faculty as an assistant professor of physics in 1959 and chaired the Department of Physics from 1969 to 1982. He played a leadership role in establishing the doctoral program in physics and founding the university chapters of Phi Beta Kappa and Sigma Xi.

Devoted Teacher and Mentor

Bob was a natural and popular teacher and while at BC taught seven different courses for nonscience majors, 11 for science majors, and 11 for graduate physics students. He retired from Boston College in 2003, having supervised 15 doctoral students.

Jack Maguire was one of his early doctoral students and had this to say:

"I have been blessed with scores of great teachers at both BC High and Boston College. But Bob Carovillano was by far the best I have ever known. He was brilliant, demanding, and empathetic. The dedication of my doctoral thesis 50 years ago stands as my tribute to a man with the looks of Elvis and the brain of an Einstein: 'To Professor Robert L. Carovillano—my teacher, mentor, and friend—who gave unstintingly of himself in an oftentimes heroic endeavor to make me a better physicist…I dedicate this thesis.'"

Bob was the son of first-generation Italian immigrants and the first in his family to attend college. He overcame infantile paralysis (polio) to become for decades an enthusiastic squash and tennis player. He was an avid "armchair athlete" for his entire adult life and rooted for the Yankees, the Red Sox, the Giants, and the Patriots with equal gusto. His stories of playing stickball in the streets of Newark, N.J., as a child and watching the Yankee greats were captivating to his family and friends.

Focus on Magnetospheric and Space Physics

In the mid-1960s Bob's research interest moved to magnetospheric and space physics, and he published on a broad spectrum of topics in theory and data analysis. These include magnetospheric energy theorems, magnetosphere-ionosphere coupling processes, substorm modeling, ionospheric electric fields and currents, ring current and radiation belt energetics and dynamics, hydromagnetic waves and plasma resonances, solar wind propagation and structure, and analysis of satellite measurements and auroral images.

Bob built up the space science program at Boston College in the years 1965–1980s despite stringent limitations on faculty hiring. His political acumen enabled the creation of a research core of professors and visiting professors. He organized one of the earliest international conferences at Boston College on "The Physics of the Magnetosphere" (1968) and an international symposium on "Science and the Future of Man" (1971).

He collaborated with numerous scientists in the field and at various times was a visiting professor at Massachusetts Institute of Technology; University of California, Los Angeles; and University of Colorado Boulder.

Bob served on and sometimes chaired advisory committees for the National Academy of Sciences, the National Center for Atmospheric Research, and the National Science Foundation. He was a member of NASA's Space Science Advisory Committee and reviewed space shuttle and satellite projects. As an officer and trustee of the Universities Space Research Association, he twice served as chairman of the Council of Institutions. In 1982–1984 he was liaison scientist at the Office of Naval Research, London (U.K.) office.

Making a Mark at NASA

Bob went on to serve as a visiting senior scientist at NASA Headquarters in the Office of Space Science, where he was responsible for supervising several space physics programs and research initiatives. Here he coordinated the various missions in the International Solar-Terrestrial Physics program and maximized their combined scientific output. In particular, his efforts nurtured data sharing and the development of coordinated analysis tools. He worked adroitly and successfully with his advisory committees to achieve and implement the goals of the entire heliospheric science community.

Bob also served in various capacities at AGU: secretary of Magnetospheric Physics and Solar-Planetary Relations, 1970–1976; section chairman of Magnetospheric Physics on numerous occasions; and member (1974–1975) and chairman (1977–1978) of the Meetings Committee. Bob cofounded the Chapman Conferences, an ongoing series of small, topical meetings that has grown into a major part of AGU's meetings program.

Vociferous in his opinions, charming, handsome, and proud, he was the very embodiment of the supposition that any obstacle can be overcome, given hard work and determination. Despite an illustrious academic career, he considered his greatest accomplishment to be his three children (Deborah, David, and Rebecca), eight grandchildren, and three great-grandchildren, of whom he was immensely proud. He was predeceased by his wife, Mary Ann, to whom he had been married for more than 30 years.

By **Robert Eather,** Keo Consultants, Brookline, Mass.; email: keoconsult@gmail.com; **Jack Maguire,** Maguire Associates, Concord, Mass.; and **Rebecca Carovillano,** CH2M Environment and Nuclear Business Group, Philadelphia, Pa.

Ocean Observatories Initiative Expands Coastal Ocean Research

OOI Coastal Arrays Community Workshop
Washington, D. C., 5–7 January 2016

Andy Cripe, *Corvallis Gazette-Times*

An Ocean Observatories Initiative (OOI) inshore surface mooring is deployed in June 2015 off the coast of Newport, Ore., from Oregon State University's (OSU) R/V Pacific Storm. *In the background, a team on OSU's R/V* Elakha *is deploying an OOI underwater glider.*

The coastal ocean provides critical services that yield both ecological and economic benefits. Its dynamic nature, however, makes it a most challenging environment to study. Recently, a better understanding of the coupled physical, chemical, geological, and biological processes that characterize the coastal ocean became more attainable.

Last January, the Ocean Observatories Initiative (OOI), a program of the National Science Foundation (NSF), held a workshop in Washington, D. C. (http://bit.ly/OOI-Workshop), to acquaint potential users with the capabilities offered by OOI systems, which were fully commissioned as of the end of 2015. A future workshop is planned for this fall on the West Coast.

OOI maintains two coastal ocean arrays: the Pioneer Array in the northwestern Atlantic and the Endurance Array in the northeastern Pacific. Each has a series of fixed moorings spanning the continental shelf, as well as mobile assets—underwater gliders and propeller-driven autonomous underwater vehicles.

Together these observatories are capable of resolving coastal ocean processes across a range of temporal and spatial scales. Such data are critical for understanding nutrient and carbon cycling, controls on the abundance of marine organisms, and the effects of long-term warming and extreme weather events.

At the workshop, Jack Barth (Oregon State University) and Glen Gawarkiewicz (Woods Hole Oceanographic Institution) presented preliminary results of recent studies and data collection efforts, stressing the rapid, ongoing changes in coastal ocean temperatures in the U.S. West Coast and East Coast shelf and slope systems. Other participants discussed connections between physics and water column nutrients, the temporal variability of key shelf currents, and the role of OOI data in assessing biodiversity.

> Scientists and educators are encouraged to use the data and provide feedback on data access ease and quality.

A key outcome of the workshop was the introduction of the OOI data portal, where participants acquired firsthand experience in data querying, plotting, and downloading of OOI data. In addition, participants had numerous opportunities to provide feedback to the OOI Cyber Infrastructure Team.

Anyone can sign up for an account to gain access to OOI data. These data are now available for plotting on the OOI data portal, and select data streams are also available. These sites will be updated with additional data and downloading formats as they become available.

NSF program managers from all relevant disciplines expressed their support for the arrays. In addition, we learned the details of how to submit proposals related to OOI data, and all the proposal submission information is available on the OOI website (http://oceanobservatories.org). Workshop participants also learned about the OOI education portal, which can bring cutting-edge ocean data and ocean science concepts to classrooms and informal science education sites.

The message from NSF was clear: OOI has entered a new phase of community engagement in which scientists and educators are encouraged to use these data, provide feedback on data access ease and quality, and in the process, expand our understanding of coastal oceans. A new era is approaching in which integrated ocean observatories will help stimulate innovative science and educational partnerships at the same time they enhance our ability to understand the changes occurring in our coastal oceans.

Jack Barth and Chris Edwards contributed to the writing of this summary. We thank NSF for sponsoring this workshop and the University-National Oceanographic Laboratory System for organizing the event, with a special thanks to Larry Atkinson and Annette DeSilva for their efforts. We also thank the workshop participants and the OOI Cyber Infrastructure Team for their continued work.

By **Robinson W. Fulweiler,** Department of Earth and Environment and Department of Biology, Boston University, Boston, Mass.; email: rwf@bu.edu; **Glen Gawarkiewicz,** Woods Hole Oceanographic Institution, Woods Hole, Mass.; and **Kristen A. Davis,** Department of Civil and Environmental Engineering, University of California, Irvine

The New Blue Economy: A Vast Oceanic Frontier

Andy Cripe, *Corvallis Gazette-Times*

Ship traffic near the port of Miami, Fla.

For centuries the sea has sustained lives and livelihoods, divulged ancient and unforeseen treasures, and stirred our dreams of remarkable new discoveries. But never in history have we had the immense opportunities now beckoning from the sea.

On the horizon is a new blue economy, an exciting oceanic frontier that offers great promise for making our nation safer, healthier, and more prosperous. The new blue economy is a knowledge-based economy, looking to the sea not for extraction of material goods but for data and information to address societal challenges and inspire their solutions.

A wide gulf often separates science from the people who need research results to protect and support them. However, the new blue economy puts science and predictive capabilities to work in a way that can fill critical, fast-rising needs across sectors. This economy is entrepreneurial and environmentally responsible, collaborative and competitive.

Now is an opportune time to reflect on the realizable potential for investing in, and building, this new blue economy.

Charting a Course from Shore to Shore

The ocean of potential waiting to be tapped spans two metaphorical shores. On one is the enormous amount of scientific knowledge we continue to gather, drawn from observations and made available through web-based platforms that let us synthesize and visualize data from innumerable sources in real time.

Through satellite and ocean-based systems, the National Oceanic and Atmospheric Administration (NOAA) and other agencies provide actionable data and other information about the sea to inform a range of predictions, from currents, waves, tides, and storm surges to water temperature, chemistry, and the marine biological system. These data and other observation-based "environmental intelligence"—timely, actionable, and reliable information—provide foresight, enabling us to make wise choices, hedge risks, and reduce the costs of uncertainty.

For example, we can anticipate a hurricane's track and intensity, evacuate vulnerable communities, anticipate resulting stresses to infrastructure, and make detailed plans should water, power, or other critical services fail. As the infrastructure for environmental intelligence, observations and predictions are the bedrock of ready, responsive, and resilient communities.

On the other shore are consumers calling for distinct tools and solutions for particular market needs. From farmers, emergency managers, and corporate executives to heads of households and heads of state, users increasingly demand spot-on information at their fingertips. They want to know whether their street, their business, or their favorite beach will be in harm's way.

To get ahead of medical emergencies, for example, coastal communities and public health officials need an app to accurately forecast harmful algal blooms. Port-by-port fog and other forecasts could substantially cut shipping costs. Because, on average, U.S. floods, including those from ocean storm surges, kill more people each year than any other weather event, emergency managers must know precisely whom to evacuate and where the sandbags should go. Maps showing wide swaths of land and highways don't zero in on such critical information.

The new blue economy offers ways to navigate between these shores, drawing on scientific and technological capabilities to create new solutions that will satisfy precise customer demands.

What Will the New Blue Economy Bring?

Envisioning value-added, tailored solutions opens a sea of opportunities. What difference would better seasonal sea ice predictions make to Arctic navigation? And open-ocean predictions of swirling eddies to cruise lines? How about forecasts of low-pH water intrusions to shellfish hatcheries? Or real-time observations of deep-ocean health to support oil spill recovery? Already, some creative entrepreneurs have developed highly valued tailored ocean temperature forecasts for the market of recreational tournament fishing.

We've learned that depending on conditions, just 90 feet of salt marsh can stop 94% of wave energy. Yet, increasingly, coastal communities vulnerable to sea level rise are being hit with tough choices about what, where, and even whether to build. With most U.S. coastal land privately owned, most shoreline protection privately designed, and nearly 5 million people already living on land less than 4 feet above high-tide levels, "living shorelines" of natural infrastructure such as salt marshes offer a resilient option upon which entrepreneurs can capitalize.

Now, as never before, we have the know-how and technology to honor the sea's fragile, finite resources while simultaneously spurring economic growth, new revenue streams, and jobs.

Making Fathoms of Data Publicly Available

Because sound science and reliable, timely data are foundational to the new blue econo-

my's success, NOAA is working to make more of this environmental intelligence available.

Each day, NOAA collects more than 20 terabytes of data—more than twice the data of the Library of Congress's entire print collection. With demand accelerating quickly, NOAA is partnering with Amazon, Google, IBM, Microsoft, and the Open Commons Consortium to bring great amounts of data to the cloud.

NOAA is eager to get information out of its laboratories and into the hands of those just as eager to transform it into predictions, solutions, and customizable value-added services. A 2013 McKinsey & Company report shows that public data can generate more than $3 trillion a year in added value, catalyzing cost savings, new and improved products, and convenience.

The hope is that in releasing data into the new blue economy, NOAA will not only spur more innovation and commerce but also encourage other agencies and groups to open up their data, contributing to an even more robust enterprise.

Matt Poole, USFWS, CC BY 2.0 (http://bit.ly/ccby2-0)

A saltwater marsh in Great Bay National Wildlife Refuge, Massachusetts.

Setting Sail

The new blue economy can look to other sectors for guidance. There is much to learn from the commercial U.S. weather enterprise, estimated to be valued in billions and perhaps tens of billions of dollars. Weather and mapping tools are now used routinely to help untold numbers of people navigate their daily lives. But a half century ago, the commercial weather industry was just a start-up, and many were skeptical about its business model.

Today the new blue economy holds similar promise. Enterprising private service providers will take a look at the coming sea change, recognize the opportunities, and roll up their sleeves. Markets imagined, and as yet unimagined, will open up. Publicly funded science, ever expanding reams of public data, and an open toolbox of technological advances will be leveraged so that consumers reap personalized value from these considerable assets.

And, in bits and bytes, the knowledge-based new blue economy will transform information into real profits, real jobs, and meaningful impacts on lives and livelihoods across the United States and the entire global community.

By **Richard W. Spinrad,** Chief Scientist, National Oceanic and Atmospheric Administration (NOAA), Washington, D. C.; email: rick.spinrad@noaa.gov

ONE FOR ALL, ALL FOR ONE

A GLOBAL RIVER RESEARCH NETWORK

By Thibault Datry, R. Corti, A. Foulquier, D. von Schiller, and Klement Tockner

More than half the length of the global river network consists of intermittent rivers and ephemeral streams (IRES), which by nature cease to flow or go completely dry at various times and places. More and more rivers and streams around the world, including some of the world's largest rivers, are becoming intermittent as humans extract their water for drinking and irrigation and because of land-use alteration and climate change [*Gleick*, 2003; *Datry et al.*, 2014].

Such drastic changes in flow regime and IRES distribution prompt fundamental questions: How are the biogeochemistry and biodiversity of river networks affected by these changes? How do these alterations vary across climatic and biogeographic regions? How can IRES be managed effectively to mitigate the ecological, social, and economic consequences of changing flow regimes?

To address these questions and follow up on a call to action in the Policy Forum of *Science* [*Acuña et al.*, 2014], a global and multidisciplinary approach is necessary. We have created a global science network, the 1000 Intermittent Rivers Project (#1000IRP on Twitter and http://bit.ly/1000IRP-Project). The project's main goal is to

Edwin Remsberg/Getty Images

An intermittent river flows at the bottom of Fish River Canyon, near Hobas, Namibia.

B. Launay

The Clauge River, Jura, France, during flowing and dry phases.

merge individual knowledge, forces, and passions through simple, consistent, and comparable joint experiments in IRES worldwide.

Plentiful IRES, Scant Knowledge

Despite the predominance of IRES, conceptual and empirical developments in river science have been derived exclusively from and for perennially flowing waters—rivers and streams that flow continuously from their source to a lake or ocean [*Acuña et al.,* 2014; *Datry et al.,* 2014]. As a result, incorporating IRES into existing models challenges some of the most persuasive paradigms in river science, including the role of river networks in global biogeochemical cycles, biodiversity, and ecosystem processes and services [*Datry et al.,* 2014].

However, because IRES have been overlooked by scientists and water resources managers, their incorporation into river science has long been limited by the scarcity of data. For example, the total length and number of perennial river channels are relatively well quantified [*Lehner et al.,* 2008; *Raymond et al.,* 2013], but the spatial extent of IRES remains unexplored at a global scale.

This is especially troublesome because IRES are the predominant water bodies in water-scarce regions. For example, IRES account for 94% of the river network in Arizona, along with 66% of California's streams and rivers [*Levick et al.,* 2008]. However, IRES are also prevalent in humid regions, and they occur from Antarctica to Amazonia [*McKnight et al.,* 1999; *Benstead and Leigh,* 2012; *Raymond et al.,* 2013; *Datry et al.,* 2014]. The global extent of river networks accounted for by IRES, their current and future distribution, their flow regimes, and their connections with perennial channels remain unknown.

We have scant knowledge about the consequences of alternating flowing, nonflowing, and dry phases to the cycling of materials along river networks and to associated biotic communities [*Datry et al.,* 2014]. As a result, the ecological, economic, and social values of IRES, and their sensitivity to human activities, are poorly explored [*Steward et al.,* 2012; *Acuña et al.,* 2014; *Datry et al.,* 2014].

Addressing the Data Shortage

Today 112 participants from 28 countries have joined the 1000IRP network (see map at http://bit.ly/1000ires-map), and more are expected to join in the near future (http://bit.ly/1000IRP_Network). However, some global regions, including Africa and Asia, remain poorly represented in this collaborative effort. We encourage colleagues from countries in these regions to join the project.

The objectives of 1000IRP are

- to raise awareness of the global prevalence and significance of IRES
- to improve the global estimate of the spatial and temporal extent of IRES and to describe their links with perennial rivers
- to conduct low-intensity field and laboratory experiments to address the key questions stated above
- to build an international network of researchers dedicated to IRES in order to support, complement, and federate current and future international projects on IRES (e.g., Science and Management of Intermittent Rivers and Ephemeral Streams (SMIRES), Intermittent River Biodiversity Analysis and Synthesis (IRBAS), EU-LIFE Temporary Rivers (TRivers)), as well as global science network initiatives (e.g., Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), Group on

Earth Observations Biodiversity Observation Network (GEO BON), Future Earth).

Early Results

During its first year (April 2015–April 2016), 1000IRP challenged the current view of the role of river networks in the global carbon cycle. Specifically, we aimed to determine the extent to which the integration of IRES affects the validity of current estimates of carbon transformation, transport, and deposition [*Battin et al.,* 2008], including carbon dioxide (CO_2) efflux rates [*Raymond et al.*, 2013], from river networks.

IRES and perennial rivers have very distinctive biogeochemical functions and tempos [*Foulquier et al.,* 2015]. Moreover, the dry phases of IRES can be biogeochemically active and may release substantial volumes of CO_2 to the atmosphere [*von Schiller et al.,* 2014]. During rewetting phases and first-pulse events (where water suddenly rewets a previously dry reach), large quantities of organic material, nutrients, and organisms that have accumulated along dry river sections can produce "hot moments" of biogeochemical transfer and transformation processes [*Corti and Datry*, 2012].

To determine the extent to which biogeochemical differences between IRES and perennial rivers affect current estimates of carbon fluxes in river networks, we require large-scale quantification of organic material accumulated along riverbeds during dry phases, as well as information on the biodegradability of this material and the reactivity of dry streambed sediments during rewetting events. We also require information about the potential environmental drivers controlling these processes, including climate, riparian cover (the plant life in and around rivers), substrate type, and duration and frequency of drying.

Each participant of 1000IRP has quantitatively sampled coarse organic matter accumulating along at least two dry river channels using standardized protocols. In addition, dry sediments and biofilms have been sampled at those sites, and detailed information about climate, flow regime, substrate, and riparian zone conditions has been compiled. All samples, obtained from 210 river reaches, have now been received at the French National Research Institute of Science and Technology for Environment and Agriculture (IRSTEA) and further processed for laboratory analyses of the biodegradability and quality of the sampled material by the different leading institutions, including ash-free dry weight (University of Grenoble), carbon-to-nitrogen ratio (University of Grenoble), CO_2 release (IRSTEA and University of the Basque Country), leaching (Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB)), and respiration of accumulated organic material and sediments (IRSTEA and University of the Basque).

We plan to analyze these data to refine current estimates of carbon transfer, deposition, and transformation, as well as CO_2 efflux rates from river networks globally.

We also plan to explore large-scale biodiversity patterns in IRES and describe biodiversity-ecosystem functional relationships within these unique ecosystems using metabarcoding, a DNA-based method that provides a rapid assessment of biodiversity. These studies will target microbes and aquatic and terrestrial biota and flora in riverbed sediments.

Widening the Network, Moving Ahead

We hope to bring 1000IRP to a wide, multidisciplinary audience; to strengthen the current network of contributors; and to encourage the inclusion of more participants and countries, especially from underrepresented areas (e.g., Africa, Asia, and Russia). This global science network is a useful example of joining forces in research to advance work on fundamental scientific questions [*Baker,* 2015].

Thanks to the success of this first year, we are planning additional joint experiments in the coming years to further advance our understanding of IRES and their overlooked geophysical, ecological, economic, and social signatures. Driving global research activities, networks, or team science from the bottom up will become more common in the future [*Baker,* 2015]. This type of grassroots effort may not only trigger subsequent research activities in IRES science but also serve as a model for global team science activities to close fundamental knowledge gaps.

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PINATU

25 YEARS LATER

Eight Ways the Eruption Broke Ground

By JoAnna Wendel and Mohi Kumar

On 3 April 1991, Sister Emma Fondevilla, a missionary based in a native Aeta village on the flanks of Mount Pinatubo, on the Philippine island of Luzon, led a group of villagers to meet with scientists from the Philippine Institute of Volcanology and Seismology (PHIVOLCS). Fondevilla and the villagers told the scientists about a series of steam eruptions on the northwestern side of the mountain.

What unfolded next would change history. Somehow, against severe odds, scientists convinced officials to evacuate more than 65,000 people living in Pinatubo's shadow. Their tireless work stands as one of the most successful hazard mitigation efforts involving a large volcanic eruption.

On 15 June at approximately 1:42 p.m. local time, Pinatubo erupted—the largest volcanic blast since Alaska's Novarupta in 1912. Its ash cloud contained 5 cubic kilometers of material—lofted to 40 kilometers high. Because a passing typhoon simultaneously brought heavy rains, fast moving flows of ash, mud, and volcanic debris called lahars rushed down the volcano, flattening towns, smashing through jungle, and smothering rice paddies and sugarcane fields. The water also mixed with falling ash, creating a cement-like substance, and many buildings caved in from the weight. More than 350 people died during the eruption, most from collapsing roofs.

Effects from Pinatubo didn't end on that date 25 years ago. Gas from the ash plume jostled weather patterns and dampened the

A 12 June 1991 eruption column from Mount Pinatubo, one of several that preceded the main eruption, seen from the east side of Clark Air Base.

effects of global warming for the next year. Lahars, which can run down a mountain after heavy rains, continued to pose threats to surrounding populations more than a decade later.

Pinatubo's eruption broke ground, literally and figuratively. Here are eight ways that Pinatubo changed the way we approach and learn from volcanic hazards.

1 First Rapid Scientific Assessment of a Volcano's History

Once Pinatubo started rumbling, PHIVOLCS set up three seismometers on its northwestern flank. After U.S. Geological Survey (USGS) scientists—part of the Survey's Volcano Disaster Assistance Program (VDAP)—arrived on 23 April, they set up a seismic network of seven stations located between 1 and 19 kilometers away from the volcano. Throughout May, seismometers recorded at least 200 small earthquakes per day.

A helicopter-mounted spectrometer—a device originally developed to monitor emissions from smokestacks—tracked dramatic increases in sulfur dioxide emissions from vents. Gas escapes as magma rises within a volcano, so this sign of moving magma, along with increasing seismicity and deformation measured by tiltmeters, led scientists to believe that an eruption was imminent.

But scientists faced a huge problem: They had had only a few weeks to learn as much as possible about Mount Pinatubo's eruptive history before it blew. Add to that another challenge: No baseline information about the volcano existed, except for one carbon date from a 1980s investigation of the area as a possible site for a nuclear power plant, said John Ewert, a geologist and member of the VDAP team deployed to the Philippines.

One of the first things the VDAP team did was consult the catalog of active volcanoes from the Smithsonian Institution's Global Volcanism Program. Pinatubo wasn't even it in it at the time, Ewert said.

VDAP scientists wasted no time. They studied layers of ancient pyroclastic flows and lahars surrounding all sides of the volcano. They collected and dated samples of charcoal. They flew in helicopters around the volcano, mapping the extent of past flows and visiting outcrops.

From the air the scientists saw that pyroclastic flows appeared "high up on ridges, or over ridges that would have blocked all but the largest flows," Chris Newhall, a volcanologist who was a part of the VDAP team in the Philippines, told *Eos*. The observations confirmed how large the impending eruption could be.

From these studies the scientists figured out that the volcano had exploded in at least six eruptive periods over the past 5000 years, short bursts of activity followed by long, quiet periods. The most recent eruption occurred 500 years earlier. What's more, surrounding villages were built on old pyroclastic flows and lahars.

2 First Successfully Mobilized Widespread Evacuations

By early June the sulfur dioxide emissions dropped sharply to around 250 tons per day. Scientists suspected this meant that the viscous, rising magma had pinched shut cracks or had cooled and lost volatiles, either way preventing gas from escaping.

Around the same time, earthquakes within Pinatubo increased in strength and duration. In early June the earthquake clusters moved from northwest of the volcano to just under its summit. On 7 June a lava dome started to surface, and on 10 June, sulfur dioxide emissions jumped to more than 13,000 tons per day. Over the next few days, explosions—some generating columns of ash and debris up to 24 kilometers high—shook the volcano (see http://on.doi.gov/28RcIJX).

These signs pointed to one thing: The volcano was about to blow. But how could scientists convince the nearly 1 million people living around the volcano that they may need to evacuate?

"One of our biggest challenges when we got to the Philippines was to actually convince people [that Pinatubo] was in fact a volcano."

The stakes were high. Just 6 years earlier, Nevado del Ruiz in Colombia had erupted and killed more than 23,000 people. A "breakdown of communications" among scientists and local authorities was partly to blame, Ewert said.

In just a few weeks, PHIVOLCS and VDAP scientists had to interpret all the data they gathered about the volcano's eruptive history and mold it into a simple warning scheme. The scheme had to be effective and easily digestible—enough so that they could convince tens of thousands of people living around the volcano, who spoke several different dialects and even different languages, to evacuate.

Language wasn't the only obstacle. "One of our biggest challenges when we got to the Philippines was to actually convince people [that Pinatubo] was in fact a volcano," Ewert said. Many locals accused the scientists from both PHIVOLCS and USGS of lying for financial gain or political reasons.

The team persevered, gathering local leaders of cities, towns, and small villages to explain the dangers and answer questions. Part of this educational campaign involved showing gruesome video footage from the Nevado del Ruiz tragedy that depicted destructive ash flows, volcanic mudflows, ashfalls, landslides, lava flows, and more (see http://bit.ly/28RA1by). Although the scientists were concerned about overstating the hazards, in the end they "judged then (and still judge) that strong images were needed to awaken people to the danger," reflected PHIVOLCS and USGS scientists in 1996 (see http://on.doi.gov/28VpMmV).

USGS

Cars and people traverse a flooded river in June 1991 after lahars wiped out bridges.

Here scientists learned a powerful lesson in hazard mitigation. As Ewert explained, “Showing people what had happened in other places in the world was much more effective than a scientist standing up in a crowd trying to explain it with interpretive dance and hand gestures.”

By early June, officials called for the evacuation of 25,000 people living in the area, including American service people at Clark Air Base and the U.S. Naval Station at Subic Bay. “By June 14 the recommended evacuation radius was 30 kilometers, which would have applied to perhaps 400,000 people,” Newhall said. Never before had such a widespread evacuation attempt been made before a volcanic eruption.

By the time the volcano erupted on 15 June, scientists and public officials had convinced more than 65,000 people to evacuate. More than 350 died during the eruption, but USGS and PHIVOLCS estimate that evacuation efforts saved between 5000 and 20,000 lives.

3 Realization of Importance of Effective Communication

In 1991, scientists had to look up information in books, make photocopies, and fax information to each other, Ewert said. This was a time before GPS and before data could be sent via satellite. Smartphones were science fiction.

In an era without a 24-hour news cycle, scientists at PHIVOLCS and USGS couldn’t supply the local populations with minute-to-minute updates, much less day-to-day, and rumors spread. One of these rumors claimed that a 3-mile-long fissure had formed after the eruption and that the nearby city of Olongapo would soon be hit by a giant lateral blast.

“Cellular telephones helped briefly, as long as their batteries lasted,” PHIVOLCS and USGS scientists reflected in 1996 (see http://on.doi.gov/28VpMmV), “but it was not until June 16 that we could tell the country that a caldera had already formed and that the climax of the eruption had probably passed.”

Today’s advanced tools would have been helpful, but “in the end, for successful natural hazard mitigation, it all comes down to how effective scientists and public officials are at communicating with each other and the public,” Ewert told *Eos*.

4 New Understanding of Triggers for Eruptions Involving Multiple Types of Magma

After the blast, investigations of cooled lava revealed that the eruption involved a mix of different types of magma, a phenomenon that had been seen before but wasn’t fully understood. Scientists had been aware of mixed-magma eruptions, but they weren’t sure what triggered them, Ewert said.

Magma can be classified into types that distinguish how much silica they contain and how viscous they are, among other characteristics. Basaltic volcanoes, like those on

Hawaii, have less viscous, "runny" magma pools. Silicic magma—made of dacite or rhyolite—is stickier and more viscous. It holds more gas that when depressurized, erupts more explosively.

Studies of lava deposits after Pinatubo exploded revealed something curious: minerals juxtaposed that would not normally coexist together had magma come from one source, Newhall explained. Thermal signatures—for example, crystals partially resorbing, chemical diffusion between crystals—suggested that magma was initially a mix of basalt and dacite prior to the eruption. But by the end of the eruption, magma was fully dacite.

Basalt magma is denser than dacite, so based on density alone, "the basalt should have been trapped beneath the dacite," Newhall said. Instead, it rose into the dacite and mixed with it. But how?

First, when the fresh, water-rich, and considerably hotter basalt hit the cooler dacite reservoir, the basalt crystallized, Newhall explained. That squeezed the basalt's water and other dissolved gases into the remaining melt. Rather than remaining confined, the volatiles escaped from the melt and "formed tiny bubbles that decreased the density of the overall basaltic magma," Newhall said. "So it was buoyant and rose into and mixed with a small amount of the dacite. That added even more volatiles."

The resulting slurry was still less dense than its surroundings, so it kept rising and was the first erupted. Eventually, the dacite itself heated enough to rise to the surface and erupt.

This magma mixing manifested as subtly rumbling quakes that at times lasted about a minute, called deep long-period (DLP) earthquakes. Long-period earthquakes indicate that magma is intruding into surrounding rock, but scientists had more frequently observed these events at depths less than 10 kilometers. Before Pinatubo, DLP earthquakes had been rarely observed and were not fully understood.

Nowadays, DLP earthquakes are "something we look for if we have a volcano that's waking up," Ewert said. Such a signal gives scientists clues into movements within the volcano's plumbing.

5 Discovery That More Gas Erupts Than Studies of Rocks Can Reveal

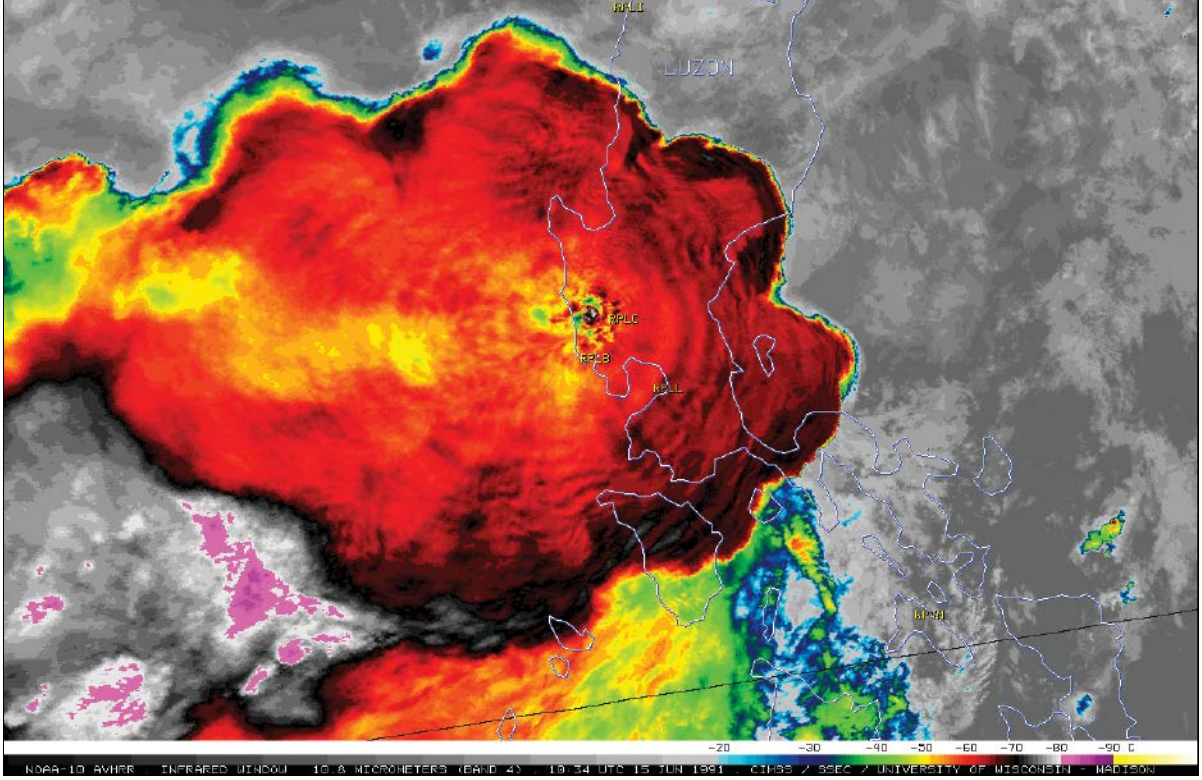
Until Pinatubo, scientists assumed that the amount of gas a volcanic eruption released—mainly water vapor, carbon dioxide, and sulfur dioxide—was governed by the volume of magma erupted and the saturation levels the gas could reach within the magma, depending on the magma's temperature. Collecting this information involves studying crystals of cooled lava after an eruption, Ewert said.

But what scientists found at Pinatubo by directly studying emissions was that "there was far more sulfur gas emitted in the atmosphere than could be accounted for" by studying crystals, Ewert said. This implied that emissions of water vapor and carbon dioxide—the gases that dominate emissions—were also more than scientists expected.

Before Pinatubo, scientists thought that gas that couldn't be dissolved into the magma escaped through vents to the surface. But a whopping 17 megatons of sulfur dioxide was released by the explosion, as measured by satellite spectrometer. This implied that large amounts of gas

Scientists install electronic tiltmeters prior to Pinatubo's eruptions. Tiltmeters measure how the ground swells during volcanic unrest.

USGS



NOAA-10 AVHRR" and CIMSS/SSEC/University of Wisconsin-Madison

The 15 June 1991 eruption of Mount Pinatubo, seen from space in thermal infrared. Warmer colors indicate colder temperatures at the top of ash cloud—the deep red indicates areas that reached -86 °C at altitudes of 20-22 kilometers. Yellow puffs trailing through the deep red show a plume from the main cloud that shot even higher (up to 40 kilometers) into the stratosphere.

could accumulate as bubbles and remain in the magma chamber, Newhall explained.

Because this excess gas makes an eruption more explosive, it might even be that such free gas is required for a Pinatubo-like eruption, Newhall said. If volatiles are already in excess, they can expand immediately once the pressure drops, without any delay from diffusing through melt.

Knowing that magmas can hold excess gas can help with forecasting efforts, Newhall explained. For example, if a volcano has been plugged since its previous eruption yet has been continuously recharged with fresh magma and gas from depth, scientists can examine the time between its eruptions to gauge whether the volcano has accumulated enough excess gas to make it particularly explosive.

6 Illumination of Details About Atmospheric Circulation

The total amount of sulfur dioxide released before and during the eruption caused the most profound effect on the stratosphere since Krakatau in 1883. The sulfuric aerosols that formed from the sulfur dioxide circled the Earth within 3 weeks and remained in the atmosphere for 3 years, reflecting enough sunlight to cool the entire planet by half a degree Celsius during that time.

However, during the following winter, Europe experienced surprisingly warm temperatures. This winter warming hadn't been observed after past volcanic eruptions, like Mexico's El Chichón in 1982. What could be going on?

Using atmospheric circulation models and computer simulations to study how Pinatubo's sulfur aerosol cloud traveled around the globe, scientists found that sulfuric aerosols reflect sunlight outward while absorbing heat from below, leading to cooling of the troposphere while heating the lower stratosphere, explained Alan Robock, an atmospheric scientist at Rutgers University in New Brunswick, N.J.

This temperature gradient strengthened the Arctic Oscillation, a wind pattern circling the Arctic. In its strong phase, the Arctic Oscillation pulls warm air from the ocean, heating northern Europe and shifting northward the global jet stream—the "river" of wind that flows around the globe.

The shifted jet stream allowed warm winds to flow over the Northern Hemisphere during the winter, Robock said. Because the jet stream flows like a wave, while Europe was receiving warm air from the south, the Middle East received colder air from the north, bringing to Jerusalem the worst snowstorm in 40 years (see http://nyti.ms/28SmqNf).

"At the time of the Pinatubo eruption, nobody knew about winter warming," Robock said. Armed with advances in modeling, plus the highly monitored atmospheric effects from Pinatubo's eruption, atmospheric scientists are better prepared to forecast the global effects of the next big eruption, he added.

7 A Bolstered Case for Human-Caused Global Warming

The eruption helped scientists definitively declare that human emissions of greenhouse gases are to blame for at least the past 60–70 years of warming.

Scientists tracked sulfur aerosols sourced from Pinatubo's eruption as they traveled around the world. For 2 years following the blast, surface temperatures cooled, as forecasted by climate models that included Pinatubo's injections into the atmosphere (see http://go.nasa.gov/29445NQ). Temperatures rose again once the cooling aerosols fell out of the atmosphere.

Pinatubo, in a sense, served as a natural climate experiment to test and calibrate models. Scientists plugged observed volcanic emissions into climate change models with and without anthropogenic emissions of greenhouse gases. In the simulations that included only volcanic eruptions, scientists didn't see the past 60–70 years of consistent warming, Robock explained.

This observation helped climate scientists sharpen their models further, confirming that humans—and the unprecedented amounts of greenhouse gases they pump into the atmosphere every year—are to blame for the warming climate. The Intergovernmental Panel on Climate Change was able to use these newly sharpened models to further support the attribution of climate change to human activities (see http://bit.ly/28SmZa1).

8 More Weight to Arguments Against Geoengineering

Some scientists have suggested geoengineering—or hacking our own atmosphere—to counteract the effects of climate change, but Pinatubo's eruption raised great concerns over whether such direct manipulation could be controlled.

One of these methods would involve injecting sulfur dioxide particles into the atmosphere just like a volcanic eruption would. Robock and other scientists agree that this kind of injection would have negative consequences. One consequence would be the destruction of the atmosphere's ozone layer, which prevents dangerous ultraviolet rays from hitting Earth.

Clouds of sulfuric acid particles—created when sulfur dioxide newly injected into the stratosphere meets water—provide surfaces on which ozone-destroying chemical reactions take place. In the 2 years after the eruption, atmospheric ozone destruction sped up, and the ozone hole over the Southern Hemisphere increased to an "unprecedented size," scientists reported (see http://on.doi.gov/28VsyIM).

Robock said that to halt global warming, humans would have to inject 100 million tons of sulfur dioxide into the atmosphere every year—that amounts to about five Pinatubo eruptions per year. Scientists generally agree that the consequences of geoengineering are too risky to attempt. It would be safer and more practical to reduce carbon dioxide emissions and "keep fossil fuels in the ground," Robock said.

Pinatubo's Legacy

In 1996, USGS and PHIVOLCS scientists wrote this sobering reminder of how if factors had been different, disaster may not have been averted at Mount Pinatubo: "In hindsight, we should have been less concerned about overstating the hazard and more concerned about speeding preparations for evacuations. Pinatubo almost overtook us" (see http://on.doi.gov/28VpMmV).

Mount Pinatubo, for now, stands relatively quiet, some 300 meters shorter than it was before it exploded 25 years ago. What might the next 25 years bring to Pinatubo? Time will tell.

Acknowledgments

Information on USGS and PHIVOLCS assessments was gathered from the book *Fire and Mud: Eruptions and Lahars of Mount Pinatubo, Philippines* (see https://pubs.usgs.gov/pinatubo).

Author Information

JoAnna Wendel, Staff Writer; and **Mohi Kumar,** Scientific Content Editor

AGU Talent Pool Programs Can Help Students with Next Career Steps

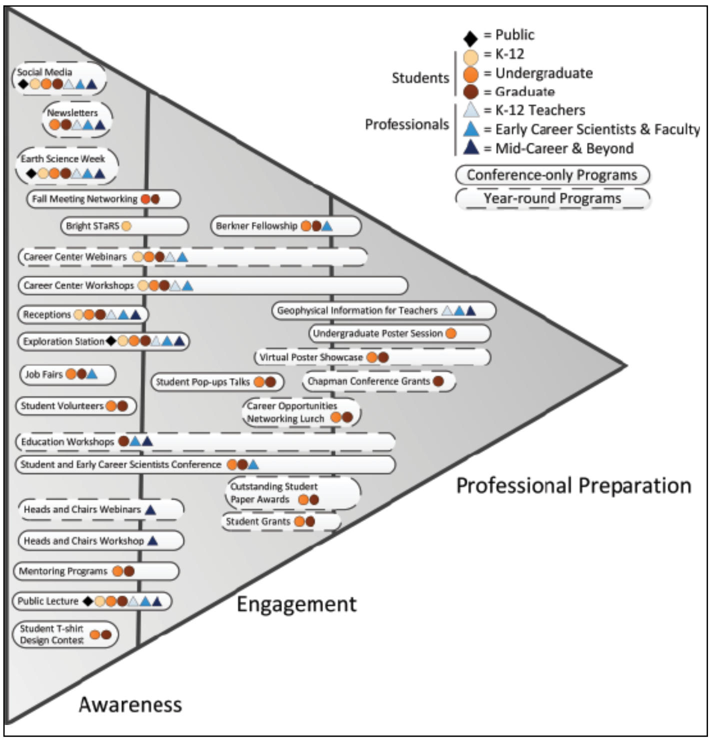


Fig. 1. AGU's Talent Pool programs are geared toward multiple audiences, including the public (diamond), students (circles), and professionals (triangles). Colors denote the level of the student (K–12, undergraduate, or graduate) and the focus of the professional (K–12, early career, or midcareer and beyond). The lengths of the bars in the triangle are not drawn to scale. Bars bridging multiple portions of the triangle indicate programs in which individuals can participate at multiple levels. The arrangement of the programs does not imply a direct linear pathway but rather denotes the nature of participation. Solid lines denote conference-only programs, and dashed lines represent year-round programs.

AGU engages several distinct audiences at a variety of career and professional stages via a suite of programs at conferences and throughout the year.

What attracts individuals to the Earth sciences and prepares them for employment? Entry into the Earth and space science workforce often involves a complex, individualized pathway. It requires training and time. It also requires commitment from academic institutions, faculty, and mentors, as well as engagement with professional societies.

In a recent National Research Council (NRC) study (http://bit.ly/NRC-Study), the Committee on Trends and Opportunities in Federal Earth Science Education and Workforce Development considered a conceptual framework of a system of opportunities and experience. In this triangular framework, many individuals first "became aware of Earth science." A small fraction of these "engage in learning the field," and an even smaller percentage of individuals "eventually prepare for a career by acquiring specialized knowledge, skills, and expertise and by exploring different employment options."

AGU engages several distinct audiences at a variety of career and professional stages via a suite of programs at conferences and throughout the year. These programs include workshops about teaching strategies, networking events for students, student conferences, virtual poster showcases for undergraduate and graduate students, and events for the public.

At first glance, these programs might appear to be unrelated, but placing this suite of programs into the NRC framework makes the connectivity clear. The programs serve different audiences, and the connections will help students and young scientists engage and bring the preparation they may need for advancing to the next step in their geoscience career. The wide range of programs enables an individual to become involved with AGU at any time "from K to gray."

Diverse Pathways

A recent report by the National Academy of Sciences (http://bit.ly/NAS-report) notes that students enter science, technology, engineering, and math (STEM) careers from a complex array of diverse pathways rather than a linear "STEM pipeline." However, three levels of involvement are typical: awareness, engagement, and professional preparation (Figure 1).

Students at various levels of involvement and progress can further their careers and engage with AGU using a variety of resources from AGU's suite of Talent Pool programing. Here are a few examples:

Undergraduate Student A attended the 2015 AGU Fall Meeting and participated in the Mentoring Program (http://bit.ly/AGU-Mentoring) but can't make it to the 2016 meeting because of funding limitations.

- **Are you a senior looking for your next step?** Explore AGU's Career Center (https://careers.agu.org) and sign up for webinars (http://bit.ly/AGU-Career-Webinars).
- **Do you have research findings to share?** Participate in the Virtual Poster Showcase (http://bit.ly/AGU-Virtual-Posters) or apply for a Student Travel Grant (http://bit.ly/AGU-Travel-Grants) for a future AGU meeting.
- **Can you reconnect with your mentor from last year?** Send your mentor an email to get back in touch.

Undergraduate Student B is planning to attend Fall Meeting for the first time in 2016.

- **Thinking about what's next?** When you register, sign up to attend the Career Opportunities Networking Lunch, and consider arriving early for the Student and Early Career Scientists Conference. When you are at the meeting, make sure you attend the Public Lecture (http://bit.ly/AGU-Lecture) to learn about a hot topic in the field.
- **Is graduate school your next step?** Participate in the Outstanding Student Paper Awards and get noticed by potential graduate advisers. Apply for some one-on-one guid-

ance in our Fall Meeting Undergraduate Mentoring Program. Attend Student Pop-Up Talks at Fall Meeting and learn more about the multiple dimensions of geoscience research.

- **Don't stop after Fall Meeting!** Sign up for emails from sections/focus groups (http://bit.ly/AGU-Sections), the Education Special Interest Group (http://bit.ly/AGU-ESIG), and the Career Center (http://bit.ly/AGU-Career-Email). Next year, consider participating in the Virtual Poster Showcase to share your latest research findings.

Graduate Student C went to the AGU Ocean Sciences Meeting in 2016 and left completely overwhelmed. Now this student is preparing to head to the Fall Meeting without his or her adviser.

- **Plan ahead.** Arrive at Fall Meeting a day early and attend the Student and Early Career Scientists Conference. Check out all of the student events (http://bit.ly/FM-Student-Events), network with peers at the Student Mixer, and consider signing up for a time slot to chat with a seasoned AGU member early in the week.
- **On a budget?** Check out our suggestions for saving money (http://bit.ly/FM-Discounts). Consider working as a student volunteer, apply for student travel grants or scholarships, and find other students who are interested in sharing a room.
- **Passionate about teaching?** Attend as many education-related events as possible at Fall Meeting. Attend the Job Fair—even if you aren't looking yet—to get an idea about what opportunities are out there.

AGU's Talent Pool programs provide numerous awareness, engagement, and professional preparation opportunities for students and early-career Earth and space scientists. Career paths are often disjointed and nonlinear, but the suite of programing is designed to provide a series of touch points between students and AGU at any time in the calendar year.

Mentors must make it clear: The onus is on you, the student, to determine which programs best meet your needs and career goals. For students who have not yet developed any career goals, focusing on awareness and engagement programs is a great place to start. Faculty, mentors, and department chairs play an integral role by helping students find the right opportunities for their advancement, whether that be a research project or entering the workforce.

By **Pranoti M. Asher,** Education and Public Outreach Manager, AGU; email: pasher@agu.org; **Claire Wilson,** Education Intern, AGU; **Erik Hankin,** Student Programs Manager, AGU; and **David Harwell,** Talent Pool Assistant Director, AGU

2016 AGU Section and Focus Group Awardees and Named Lecturers

On behalf of AGU leaders and staff, section and focus group selection committees, and the entire AGU community, we extend our heartfelt congratulations to all of this year's section and focus group awardees and named lecturers!

Listed below are scientists, in various stages of their careers, who have been selected by AGU sections and focus groups to receive awards in 2016. Also listed are scientists who were chosen to present lectures under the annual Bowie Lecture Series as well as the Section and Focus Group Named Lecture Series.

The Bowie Lecture was inaugurated in 1989 to commemorate the fiftieth presentation of the William Bowie Medal, which is named for AGU's first president and is the highest honor given by AGU. Bowie lecturers in the list below are denoted by asterisks. Named lecturers are designated by sections and focus groups to honor distinguished scientists in their respective fields of science.

We thank all sections and focus groups for giving these honors to their well-deserving colleagues. These awardees/lecture recipients represent some of the most innovative minds in their fields. We recognize their continuing meritorious work and service toward the advancement and promotion of discovery in Earth and space science for the benefit of humanity.

We look forward to recognizing their achievements at the 2016 AGU Honors Tribute, to be held 14 December in San Francisco.

Eric Davidson, AGU President-Elect and Chair, AGU Council; and **Sam Mukasa,** 2015–2016 Chair, Honors and Recognition Committee; email: AGU_Unionhonors@agu.org

Atmospheric Sciences Section

Ascent Award
Alex Hall, University of California, Los Angeles
Christian Jakob, Monash University
Eric Maloney, Colorado State University
Adam Scaife, Met Office Hadley Centre
Susan Van den Heever, Colorado State University

James R. Holton Junior Scientist Award
Yuan Wang, California Institute of Technology

Yoram J. Kaufman Unselfish Cooperation in Research Award
Karen Rosenlof, National Oceanic and Atmospheric Administration

*Bjerknes Lecture**
Isaac Held, National Oceanic and Atmospheric Administration

*Charney Lecture**
Daniel Jacob, Harvard University

Biogeosciences Section

Sulzman Award for Excellence in Education and Mentoring
Erika Marin-Spiotta, University of Wisconsin

Cryosphere Focus Group

Cryosphere Early Career Award
John Paden, University of Kansas

Nye Lecture
Christina Hulbe, University of Otago

Earth and Planetary Surface Processes Focus Group

G. K. Gilbert Award in Surface Processes
Christopher Paola, University of Minnesota

Luna B. Leopold Award
Alison Duvall, University of Washington

Sharp Lecture
Alison Duvall, University of Washington

Earth and Space Science Informatics Focus Group

Leptoukh Lecture
Cynthia Chandler, Woods Hole Oceanographic Institution

Geodesy Section

Geodesy Section Award
Emma Hill, Earth Observatory of Singapore

Ivan I. Mueller Award for Service and Leadership
Eric Fielding, NASA Jet Propulsion Laboratory

*William Bowie Lecture**
Mark Simons, California Institute of Technology

Geomagnetism, Paleomagnetism, and Electromagnetism Section

William Gilbert Award
Ron Shaar, Hebrew University of Jerusalem

*Bullard Lecture**
Nils Olsen, Technical University of Denmark

Global Environmental Change Focus Group

GEC Bert Bolin Award/Lecture
Alan Betts, Atmospheric Research

GEC Early Career Award
William Anderegg, Princeton University

Schneider Lecture
David Battisti, University of Washington

Tyndall Lecture
Waleed Abdalati, University of Colorado

Hydrology Section

Early Career Hydrologic Science Award
Ciaran Harman, Johns Hopkins University

Horton Research Grant
Noah Jemison, University of Illinois at Urbana-Champaign
Hadley McIntosh, Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science
Katalyn Voss, University of California, Santa Barbara

Hydrologic Sciences Award
Amilcare Porporato, Duke University

*Langbein Lecture**
James Kirchner, ETH Zurich

Witherspoon Lecture
Paolo D'Odorico, University of Virginia

Mineral and Rock Physics Focus Group

Mineral and Rock Physics Early Career Award
Heather Savage, Columbia University

Mineral and Rock Physics Graduate Research Award
Jeffrey Pigott, Case Western Reserve University
Lucas Pimienta, École Normale Supérieure Paris

Jamieson Student Paper Award
Ting Chen, Stony Brook University
Xintong Qi, Stony Brook University
Xuebing Wang, Stony Brook University

Natural Hazards Focus Group

Natural Hazards Focus Group Award for Graduate Research
Tarsilo Girona, Georgia Institute of Technology

Gilbert F. White Lecture
Roger Pulwarty, National Oceanic and Atmospheric Administration

Near-Surface Geophysics Focus Group

GSSI Near-Surface Geophysics Student Grant
Han Deng, Brigham Young University

Nonlinear Geophysics Focus Group

Donald L. Turcotte Award
Yavor Kamer, ETH Zurich

Lorenz Lecture
Vladimir Zakharov, University of Arizona

Ocean Sciences Section

Ocean Sciences Voyager Award
Laurent Bopp, Laboratoire des Sciences du Climat et de l'Environnement

Carson Lecture
Virginia Armbrust, University of Washington

Sverdrup Lecture
Susan Wijffels, Commonwealth Scientific and Industrial Research Organisation

William S. and Carelyn Y. Reeburgh Lecture
Ronald Oremland, U.S. Geological Survey

Paleoceanography and Paleoclimatology Focus Group

Dansgaard Award
Jerry McManus, Columbia University

Planetary Sciences Section

Ronald Greeley Early Career Award in Planetary Science
Edwin Kite, University of Chicago

Whipple Award and Lecture
John Spencer, Southwest Research Institute

*Shoemaker Lecture**
Meenakshi Wadhwa, Arizona State University

Seismology Section

Keiiti Aki Young Scientist Award
Zhongwen Zhan, California Institute of Technology

*Gutenberg Lecture**
Karen Fischer, Brown University

Space Physics and Aeronomy Section

Basu United States Early Career Award
Colin Komar, NASA Goddard Space Flight Center

Fred L. Scarf Award
Kok Leng Yeo, Max Planck Institute for Solar System Research

Space Physics and Aeronomy Richard Carrington Education and Public Outreach Award
Ramon Lopez, University of Texas at Arlington

Sunanda and Santimay Basu Early Career Award in Sun-Earth Systems Science
Joseph Olwendo, Pwani University

Nicolet Lecture
Tom Cravens, University of Kansas

*Parker Lecture**
Tom Woods, University of Colorado

Study of the Earth's Deep Interior Focus Group

Study of the Earth's Deep Interior Graduate Research Award
Harriet Lau, Harvard University
Joseph O'Rourke, California Institute of Technology

Tectonophysics Section

Jason Morgan Early Career Award
Whitney Behr, University of Texas at Austin

*Birch Lecture**
Maya Tolstoy, Lamont-Doherty Earth Observatory

Volcanology, Geochemistry, and Petrology Section

Hisashi Kuno Award
Esteban Gazel, Virginia Polytechnic Institute and State University

Norman L. Bowen Award and Lecture
Dante Canil, University of Victoria
Tim Elliott, University of Bristol

*Daly Lecture**
Richard Walker, University of Maryland

Joint Award: Geodesy, Seismology, and Tectonophysics Sections

Paul G. Silver Award
Robert Reilinger, Massachusetts Institute of Technology

Joint Lecture: Biogeosciences and Planetary Sciences Sections

Sagan Lecture
Nathalie Cabrol, SETI Institute and NASA Ames Research Center

Joint Lecture: Paleoceanography and Paleoclimatology Focus Group and Ocean Sciences Section

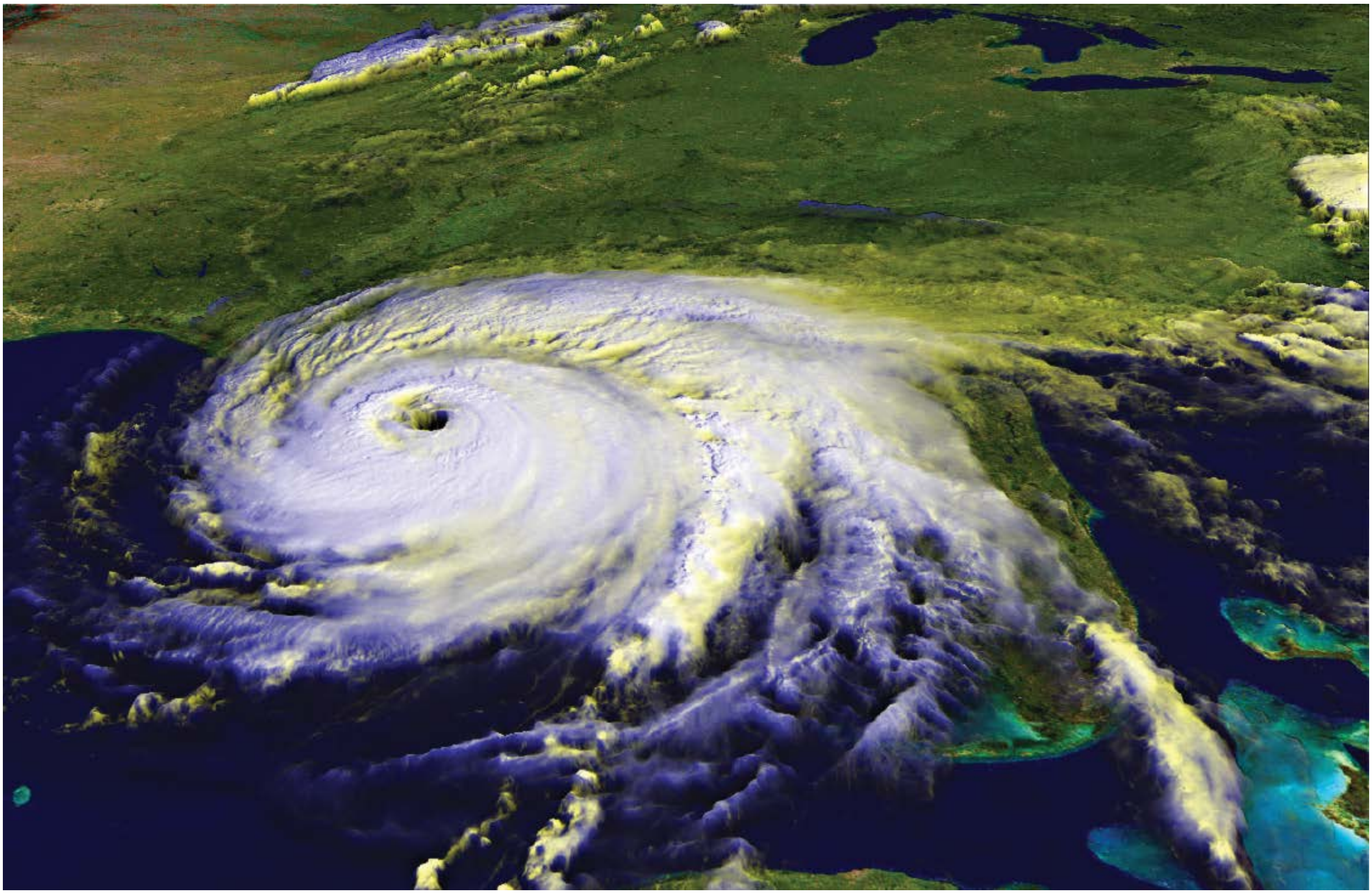
Emiliani Lecture
Bette Otto-Bliesner, National Center for Atmospheric Research

Joint Student Grant: Atmospheric Sciences and Space Physics and Aeronomy Sections

Dr. Edmond M. Dewan Young Scientist Scholarship for Atmospheric Sciences and Space Physics
Michael Allen, University of Western Ontario

*Asterisks denote Bowie lecturers.

How Tropical Cyclones Influence Photosynthesis



NASA-Goddard Space Flight Center, data from NOAA GOES

A computer-generated composite shows Hurricane Ivan, by then a category 3 storm, making landfall on 16 September 2004.

Along with the destruction they cause for human civilization, tropical cyclones play a vital role in nourishing onshore ecosystems with freshwater. As a tropical storm tracks inland, it creates thunderstorms via a common convective process. In the southeastern United States especially, these storms can represent a large fraction of the total rainfall during hurricane season, which extends from 1 June through 30 November. Here *Lowman and Barros* use the Duke Coupled Hydrology Model with Vegetation in two different scenarios—with and without the influence of tropical cyclones—to assess how such storms affect gross primary productivity in the southeastern United States.

The model includes a large number of variables, such as soil characteristics and vegetation type, to track the movement of water through a region as realistically as possible. Using the scientific understanding of plant physiology, specifically how processes in light and photosynthetic reactions scale with carbon assimilation, the researchers could also calculate the total amount of photosynthesis occurring in the region using the same model.

To understand the effect of the storms, the researchers ran the model with retrospective data from 2002 to 2012 and compared the real-world results with a second simulation in which all tropical cyclones had been removed and replaced with average weather. Many variables proved to be important in determining how much influence a cyclone would have on gross primary production, but the timing and trajectory of cyclones proved to be especially important.

In wet years with more tropical cyclones than average, such as 2004 and 2005, the storms increased gross primary productivity by up to 9%—the equivalent of 3–5 million grams of carbon per square meter across the study region. In dry years the cyclones increased carbon uptake by 4%–8% relative to the simulations where the storms had been replaced with average weather.

Under the current climate trends, tropical cyclones are expected to increase in the future, and thus the authors argue that understanding how they affect vegetation, carbon fixation, and drought will become only more important with time. (*Journal of Geophysical Research: Biogeosciences,* doi:10.1002/2015JG003279, 2016) **—David Shultz, Freelance Writer**

The Mathematics of Braided Rivers

To a casual onlooker, a winding river may elicit visions of canoeing, fishing, or swimming, but for some scientists, flowing bodies of water bring to mind mathematics. Rivers can be treated as experiments in fluid dynamics, and researchers have long been interested in modeling how flowing water sculpts the land around it and vice versa.

Braided rivers are composed of multiple channels separated by short slices of land between the river's true edges; such rivers are especially difficult to model due to their variable boundaries and rapidly changing local topography. Here *Redolfi et al.* calculate a new, dimensionless indicator that reflects the shape of the riverbed and allows the team to derive other mathematical relationships important to modeling the flow of braided rivers.

The new indicator, called α, describes the shape of the riverbed when represented as a statistically averaged cross section. Some rivers' cross sections are U-shaped—flaring out gradually from the base before shooting almost straight up near the banks; others are Y-shaped—wide at the top, but quickly narrowing to a very thin trough at depth; still others are somewhere in the middle—V-shaped with linearly slanted walls. Higher α values correspond to Y-shaped riverbeds, and lower ones produce U-shaped profiles. It's important to note that α symbolizes an average representation of the river's form over a period of uninterrupted distance known as a reach. Accordingly, all of the mathematical relationships revealed by the α indicator are also reach-scale in nature.

Generally speaking, a host of laboratory and field experiments suggest that braided rivers tend to have Y-shaped profiles, and single-thread rivers have more U-shaped profiles. The mathematics indicates that different profiles result from different hydrological regimes, bed material, and valley characteristics. When rivers have a high degree of confinement, meaning they occupy all the possible width that their surroundings permit—a river flowing through a thin, high-walled canyon, for instance—the profile moves toward a U shape.

When a value D, representing the depth of a river, is raised to the αth power, it produces a close approximation of the total width of the river covered by water. In a nonbraided river this number would be just the bank-to-bank "wetted width," but in braided rivers the measurement becomes complicated because ridges of land also contribute to the total width.

James Brasington

The confluence of the Rees and Dart rivers in New Zealand.

The α indicator offers advantages over previous techniques because it does not depend on how much water is flowing through the river at any given time. Scientists can use the new metric to calculate other properties of braided rivers, such as how shear stress from the flowing water is distributed along a reach and the total volume of sediment particles moving through the river.

The new mathematics show that physical properties of braided rivers can be explained by a relatively simple power law, an insight that should allow scientists to more accurately model these bodies of water with less need for intensive fieldwork to nail down specific river parameters. The authors note that the time and resources saved will be a definite boon to the field as water management becomes increasingly important in the face of climate change and growing world population. (*Water Resources Research,* doi:10.1002/2015WR017918, 2016)
—David Shultz, Freelance Writer

Defining the Onset and End of the Indian Summer Monsoon

Every year, the Indian Meteorological Department officially predicts the onset date of the Indian summer monsoon (ISM), which is characterized by heavy rainfall throughout the season. However, this prediction is based on a regional definition of ISM onset that has little bearing on the overall seasonal variation of the monsoon and prevents precise evaluation of model simulations developed to predict its timing. In a new paper, *Noska and Misra* propose a new, objective definition for ISM onset that is based on measurements of average rainfall across India.

The researchers used rain gauge data collected between 1902 and 2005 to develop calculations for an objective definition of both the start and end dates of the ISM in a given year. Their new definition is consistent with other important ISM characteristics, including atmospheric temperature gradient reversal, changes in wind direction, and ocean heat transport. It also aligns with the variability associated with El Niño and La Niña events.

To determine the beginning and end of the ISM, the researchers consider the daily rainfall anomaly—the difference between a given day's rainfall and the annual mean—averaged over all of India. The onset of ISM is declared when the all-India average daily rainfall begins to exceed the all-India averaged annual mean in a sustained manner. The end of the ISM is declared when the all-India average daily rainfall begins to recede from the all-India average annual mean.

The authors argue that the strength of the new definition lies in its simplicity: It is based on the sole variable of rainfall. This simplicity could enable people outside of the scientific community to more easily track and understand ISM variability. The new definition could also improve prediction of anomalous rainfall patterns for a given summer season. (*Geophysical Research Letters,* doi:10.1002/2016GL068409, 2016) **—Sarah Stanley, Freelance Writer**

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- *Eos* is not responsible for typographical errors.

* Print-only recruitment ads will only be allowed for those whose requirements include that positions must be advertised in a printed/paper medium.

ATMOSPHERIC SCIENCES

Hydroclimatology and hydrometeorology PhD student at the University of Vermont

A multi-year Graduate Research Assistantship position is available as part of a research study on Resilience to Extreme Events in Social Ecological Systems of the Lake Champlain Basin. We seek students interested in pursuing PhD level research in the areas of hydroclimatology, climate data interpretation and analysis of hydrometeorological events within a changing climate, or closely related fields. Candidates should enjoy being part of an interdisciplinary team of researchers (i.e., faculty, graduate students, undergraduates, and stakeholders) working toward identifying strategies that improve water quality resilience within the Lake Champlain Basin.

Qualifications: At a minimum, a Bachelor's (Master's preferred) in engineering, climatology/atmospheric science, physical geography, environmental science, or closely related field with research interests in climate processes and dynamics, hydrology, extreme value statistics and mathematical modeling applied to inter-disciplinary environmental research.

Start date January 1, 2017, or as soon as possible thereafter. This position comes with a research assistantship that is renewable through May 2021. Candidates should enroll in a UVM graduate program for the spring term if possible, but should be on campus by June 1, 2017 to begin work. Please contact Arne Bomblies (Arne.Bomblies@uvm.edu) for more information.

To apply: please send CV, names and contact information for three references, and a cover letter outlining research interests, expertise and availability to epscor@uvm.edu and reference Position ID GRA#004.

For detailed job descriptions visit: http://www.uvm.edu/EPSCoR/jobs

BIOGEOSCIENCES

Lake PhD Student at the University of Vermont

We seek an enthusiastic and motivated student interested in nutrient biogeochemistry and limnology, who is interested in exploring how extreme events impact water quality/biogeochemistry in diverse lake systems of different trophic states and physical configurations. The student's dissertation research will utilize an advanced in-situ lake monitoring network to develop and address fundamental research questions regarding the drivers of nutrient, carbon and phytoplankton response to such events. Basic dissertation research questions will focus on environmental controls on the response of a lake to extreme events, such as antecedent conditions, phenology, and event severity and how these manifest in lake systems that

Freie Universität Berlin

Department of Earth Sciences - Institute of Geological Sciences

Professorship in Planetary Geology

limited to 5 years, salary grade: W2, reference code: Planetology

The successful applicant will cover the area named above in research and teaching. Appointment requirements are governed by Article 100 of the Berlin Higher Education Act (Berliner Hochschulgesetz).

Candidates will have excellent, internationally recognized expertise in Planetary Geology and Comparative Planetology, verified by a comprehensive publication record. She or he will have profound experience in university teaching and in supporting junior scholars. Additionally, successful candidates will have experience in acquiring funding for, and carrying out, sponsored research projects on a larger scale including involvement in the management and implementation of knowledge and technology transfer (such as industry cooperations, inventions/patents and spin-offs).

The main focus of the Professorship will be in the field of Planetary Geology and Comparative Planetology, including but not limited to: the evolution of planetary bodies; the role of volcanism, water, ice and wind in the formation processes of planetary surfaces; the chemical and mineralogical composition of surfaces.

The research approach mainly applies and develops methods of planetary remote sensing and planetary GIS systems. An intensive cooperation with other research groups is desired, including interdisciplinary cooperation with physical, chemical and astrobiological disciplines and the new Collaborative Research Centre (SFB Transregio) 170. The appointee will have access to the geo-science network geo-X. that offers contacts and possibilities for grants.

Applications quoting the **reference code** should include a CV, copies of all certificates of academic qualification, a list of publications, evidence of teaching competence (such as courses previously taught) as well as of involvement in ongoing and future research endeavours, joint research projects and externally funded projects. If applicable, applications should also include information on industrial cooperations, inventions/patents and spin-offs.

All materials, including a private postal and an e-mail address must be received electronically and in hard copy no later than **August 29th, 2016** at Freie Universität Berlin, Fachbereich Geowissenschaften, Dekanat, Frau Herm, Malteserstr. 74 - 100, D-12249 Berlin or via e-mail: doherm@campus.fu-berlin.de

Application guidelines and general information on the appointment procedure as well as requirements for professorships at Freie Universität Berlin can be found at www.fu-berlin.de/praesidialamt. For additional details, please visit www.fu-berlin.de/en and www.geo.fu-berlin.de/en. Freie Universität Berlin is an equal opportunity employer.

differ in trophic state, watershed:lake area, and watershed landcover (forest vs. agricultural).

Qualifications: MS research experience working in similar biogeochemical systems is preferred. Experience working with and deploying in-situ sensors, as well as conducting advanced statistical analyses requisite for interpretation of large environmental datasets are desirable. Experience working on the water in marine or freshwater environments is required and operating and trailering small vessels is desirable.

This position comes with a research assistantship renewable through May 2021. Candidates should enroll in a UVM graduate program for the spring term if possible, but should be on campus by June 1, 2017 to begin work. Please contact Andrew Schroth (Andrew.Schroth@uvm.edu) for more information.

To apply: please send CV, names and contact information for three references, and a cover letter outlining research interests, expertise and availability to epscor@uvm.edu and reference Position ID GRA#002.

For detailed job descriptions visit: http://www.uvm.edu/EPSCoR/jobs

Soil-Watershed PhD Student at the University of Vermont

We seek an enthusiastic and motivated student with expertise in biogeochemistry, soil science, catchment hydrology or related fields with a focus on exploring the biogeochemical linkages between terrestrial and aquatic systems during extreme climate events. The student's dissertation research will utilize an advanced in-situ riparian soil and stream monitoring network to develop and address fundamental research questions regarding environmental controls on nutrient (P, N, Fe) and carbon efflux from landscape to streams in forested and agricultural catchments of the Lake Champlain Basin. Basic dissertation research questions will focus on the drivers of the response of soil and stream water quality to extreme events.

Qualifications: Previous experiences working with in-situ sensors in soils and/or streams are desirable, and enthusiasm and physical capability to conduct field intensive research across a range of weather conditions are required. MS research experiences studying nutrient/carbon dynamics in forested and/or agricultural riparian soils and/or catchments are also preferable.

This position comes with a research assistantship that is renewable through May 2021. Candidates should enroll in a UVM graduate program for the spring term if possible, but should be on campus by June 1, 2017 to begin work. Please contact Carol Adair (Carol.Adair@uvm.edu) for more information.

To apply: please send CV, names and contact information for three references, and a cover letter outlining research interests, expertise and availability to epscor@uvm.edu and reference Position ID GRA#001.

For detailed job descriptions visit: http://www.uvm.edu/EPSCoR/jobs.

EARTH AND SPACE SCIENCE INFORMATICS

Tenure-line Position in Energy Resources Engineering at Stanford University

The Department of Energy Resources Engineering at Stanford University invites applications for a tenure-line faculty appointment. The position is at the assistant professor level. It is desired that the selected candidate be able to start no later than Autumn 2017. For more information about the Energy Resources Engineering Department, see the Stanford ERE web page at http://pangea.stanford.edu/ERE/.

The Department of Energy Resources Engineering focuses on a wide range of activities related to the recovery of the Earth's energy resources (e.g., hydrocarbons, geothermal, and other renewables). The department has core areas of expertise in computational (simulation and optimization) and experimental approaches to energy production. ERE offers degrees in both energy resources engineering (B.S., M.S., Ph.D.) and petroleum engineering (M.S., Ph.D.).

We seek scholars with a Ph.D. in an engineering or computational discipline who possess novel and innovative

The Geosensing Systems Engineering (GSE) Graduate Research Program at University of Houston (UH) has funding available from NASA's SERVIR program for qualified Ph.D. students who are interested in conducting research using satellite altimetry, SAR/InSAR, and GRACE data for applications in water resources management.

Candidates with geodetic background and strong programming skills are preferred. Please contact Dr. Hyongki Lee at hlee@uh.edu for more details.

University of Basel

Professorship in Atmospheric Sciences (open rank)

The Department of Environmental Sciences at the Faculty of Science, University of Basel invites applications for a Professorship in Atmospheric Sciences (open rank).

We are seeking a scientist with a strong record of innovative and high-impact research in the broader fields of Atmospheric Sciences.
The successful candidate will help to develop and strengthen the division of Geoscience within the Department of Environmental Sciences (http://duw.unibas.ch).

Candidates applying are expected to demonstrate internationally recognized scholarly activities with a strong record of externally funded research. Preference is given to candidates who investigate the interactions between the atmosphere and the Earth's surface. Particularly encouraged to apply are candidates interested in either of the following research areas:

1) Atmospheric trace gas fluxes- and transport processes and their interaction with the biosphere, pedosphere and/or hydrosphere.
2) Feedback and feedforward mechanisms between climate, trace gasses, aerosols and energy.
3) Quantification of chemical conversion processes in the atmosphere.

The successful candidate is expected to teach basic courses in meteorology and climatology both at the undergraduate (in german and english) and graduate (in english) levels, and to contribute to the development of the degree programs BSc and MSc in Geosciences, in particular the major in geography and climatology, as well as the degree programs BA and MA in Geography.

The University of Basel is an equal opportunity and family friendly employer committed to excellence through diversity. To increase the number of women in leading academic positions, the University strongly encourages applications from women.

Application / Contact

Applications including letter of motivation, CV, list of publications, and a statement of research and teaching interests should be sent by e-mail as one pdf-document to Prof. Dr. Jörg Schibler, Dean of Faculty of Science, University of Basel, Klingelbergstrasse 50, 4056 Basel, Switzerland, at: dekanat-philnat@unibas.ch.

Please address requests for further information to Prof. Dr. Moritz Lehmann, Dean of Research (moritz.lehmann@unibas.ch).
The application deadline is 10 September 2016.

www.unibas.ch

research capabilities in energy transitions engineering, renewable energy integration and optimization, and renewable resource planning and optimization. We envision intellectual engagement in one or more of the following areas:

Computational approaches for the design and dispatch of renewable or hybrid renewable-fossil energy systems

Optimal control of renewable- and flexible-power systems operation

Energy storage system design, including optimization, valuation, and novel technology evaluation

Multi-criteria optimization focusing on challenges associated with novel energy technologies including energy generation, land use, water consumption, materials abundance, and scalability

Analysis of technological change, including rigorous modeling of innovation, technology scale-up and deployment

We will begin reviewing applications on September 1, 2016 and will continue until a suitable candidate is identified. To apply, please submit the following application materials: cover letter, curriculum vitae with a complete list of publications, a statement outlining research and teaching interests, the names of three references including e-mail addresses, and copies of up to five selected papers published in refereed journals over the past three years. Please apply online at https://academicjobsonline.org/ajo/jobs/7416 in electronic format (pdf only).

Stanford University is an equal opportunity employer and is committed to increasing the diversity of its faculty. It welcomes nominations of, and applications from women, members of minority groups, protected veterans and individuals with disabilities, as well as from others who would bring additional dimensions to the university's research, teaching and clinical missions.

HYDROLOGY

Postdoc Position in Hydrology Available at NASA/JPL

NASA's Jet Propulsion Laboratory (JPL), California Institute of Technology (Caltech) seeks a recent Ph.D. graduate with a unique background in hydrology, remote sensing, computer programming, Geographic Information Systems (GIS), and a demonstrated record of multiple first-author publications. The position will be part of the Caltech Postdoctoral Scholars Program at JPL in the Atmospheric Physics and Weather Group, Earth Science Section.

The research will involve exploring almost all components of the water cycle and using various datasets from satellite remote sensing, in situ, or reanalysis. The emphasis will be on hydrology of cold regions including high latitudes and mountainous regions. Past experience in using precipitation from satellite (such as those used in the Global Precipitation Measurement mission; GPM), total water storage from the Gravity Recovery And Climate Experiment (GRACE), and global hydrologic modeling is highly desirable. The Postdoctoral Scholar will build a framework for assessing regional to basin-scale water budget and hydrologic changes, interact with GPM and GRACE science team members, and publish scientific papers on the developed framework and results.

Dr. Ali Behrangi in JPL's Earth Science Section will serve as the primary advisor to the selected candidate. The appointee will also work with the project team at JPL and external collaborators.

Caltech's Postdoctoral Scholar Program awards positions for a minimum of one year, and may be renewed up to a maximum of three years. Candidates who have received their Ph.D. within the past five years since the date of their application are eligible. Caltech and JPL are equal opportunity/affirmative action employees. Women, minorities, veterans, and disabled persons are encouraged to apply. The position will remain open until filled, with a desired (but not required) start date of September 2016.

Please send a letter clearly describing how this project fits with your background and interest, a CV, and a list of three references (with telephone numbers, postal and email address) with contact info to: abehrang@jpl.nasa.gov.

INTERDISCIPLINARY

National Watershed Integrity Mapping

National Watershed Integrity Mapping (position EPA-ORD-NHEERL-WED-2016-03). Qualifications include: doctoral degree in aquatic ecology, ecohydrology, watershed hydrology (with a background in aquatic ecology, spatial analysis, and statistics), or a closely related field within five years of the desired starting date, or completion of all requirements for the degree should be expected prior to the start date. Experience in watershed or statistical modeling and spatial analyses at broad spatial scales and use of aquatic monitoring data and GIS analyses is desired. Note that the position is funded through the Oakridge/ORISE program. The full project description can be found at https://www.zintellect.com/Posting/Details%5C2219.

PhD positions

12 PhD scholarships available within the Research Training Group "The Ecology of Molecules" at the University of Oldenburg, Germany: https://www.icbm.de/en/scientific-projects/ecomol/phd-programme/

EARTH AND ENVIRONMENTAL SCIENCES
UNIVERSITY OF MICHIGAN

Faculty Positions at the University of Michigan

The Department of Earth and Environmental Sciences and the Program in the Environment at the University of Michigan anticipate two openings for joint tenure-track assistant professors for university-year appointments starting September 1, 2017. We are particularly interested in candidates whose strengths complement existing research programs within the Department and the Program.

Biological Oceanography: We encourage applications from candidates whose research interests encompass the role of biology in ocean chemistry, marine geology, or physical oceanography. Specific areas of interest include (but are not limited to) carbon and nitrogen cycling in the ocean, physical-biological interactions, biomineralization of marine organisms, sediment biogeochemistry, and the impact of global change on marine life and biogeochemistry. The position is open to candidates who use field, lab, and/or modeling approaches at scales ranging from molecular to global.

Geobiology: We encourage applications from candidates whose research interests encompass interactions between biology and geology, geochemistry, or hydrology. Specific areas of interest include (but are not limited to) soils, biomineralization, microbe-mediated water-rock interactions, nanoparticles, microbe-metal interactions, and organic geochemistry. The position is open to candidates who study any organism (e.g., microbes, fungi, plants, and animals), at all scales (molecular to global, individual to community), and with various approaches (e.g., isotopic, molecular, spectroscopic).

The successful candidate is expected to establish an independent research program and contribute to both undergraduate and graduate teaching. Applicants must have a Ph.D. at the time of appointment, and should submit a CV, statement of current and future research plans, a statement of teaching philosophy and experience, and evidence of teaching excellence, if available. Letters of recommendation from three to five references should be submitted directly by the recommender, before the application deadline, using a link that will be provided once the application is submitted.

Information about the Department can be found at www.lsa.umich.edu/earth and information about the Program can be found at www.lsa.umich.edu/pite.

To apply please go to: http://apps-prod.earth.lsa.umich.edu/search16/index.php. Complete the online form and upload the required application documents as a single PDF file. If you have any questions or comments, please send an email message to Michigan-Earth-Search@umich.edu.

The application deadline is September 8, 2016 for full consideration, but applications will continue to be reviewed until the position is filled. Women and minorities are encouraged to apply. The University of Michigan is supportive of the needs of dual career couples and is an equal opportunity/affirmative action employer.

NOTICE OF VACANCY
WASHINGTON STATE UNIVERSITY
Laboratory for Atmospheric Research
Department of Civil and Environmental Engineering
Voiland College of Engineering and Architecture
Position 55848

Washington State University, Department of Civil and Environmental Engineering and the Laboratory for Atmospheric Research (LAR) invite applications for a permanent 9-month tenure-track faculty position at the assistant to associate professor level on the Pullman campus with an effective start date from January 1, 2017 to August 16, 2017. This position is part of WSU's priority to build a diverse faculty; thus, female and minority candidates are strongly encouraged to apply.

Candidates are sought with expertise in numerical modeling related to air quality, atmospheric chemistry, and climate change at urban to regional scales. The successful applicant will help lead and grow the WSU AIRPACT air quality forecast system operation. The selected applicant will teach graduate and undergraduate air quality and environmental engineering courses, direct graduate student research, and develop a strong extramurally funded research program. The position requirements include:
1) expertise with urban to regional scale atmospheric chemistry models with applications to air quality, atmospheric chemistry, and/or climate change, 2) a record of research accomplishments demonstrated by peer reviewed publications and/or extramural grants, 3) demonstrated ability to work with diverse, interdisciplinary teams in a collaborative manner, 4) a record of outreach, mentoring, or teaching to diverse student populations, and 5) an earned Ph.D. or equivalent degree in a relevant engineering or science field. In addition, experience using remote sensing and in situ observations to evaluate and improve models and participation in the design and implementation of field campaigns is desirable.

Applicants should apply online at https://www.wsujobs.com by submitting the following: a cover letter, a detailed resume, a statement of research and teaching interests, and a list of five references with contact information. Screening of candidates will begin September 1, 2016, but applications will be accepted until the position is filled.

WASHINGTON STATE UNIVERSITY IS AN EQUAL OPPORTUNITY/AFFIRMATIVE ACTION EDUCATOR AND EMPLOYER.

Postcards from the Field

Hi, Everyone.

I am a field assistant here at Mount Magruder in Nevada. This is not a pyramid but a Cambrian period reef that has become exposed. Also, as of right now it is 102°F. Help!

—Lisa Mowery

View more postcards at *http://americangeophysicalunion.tumblr.com/tagged/postcards-from-the-field.*